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Guidelines for the safe use of explosives under water

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FOREWORD

The project to prepare these *Guidelines* was undertaken to provide the specialist guidance needed when explosives are used in support of underwater operations.

The project was initiated by UEG, the original research and information group for the offshore and underwater engineering industries, and was included in the Marine Technology Directorate Ltd's (MTD's) portfolio of multi-sponsor projects when UEG was absorbed within MTD. Continuity of purpose was maintained through the Project Manager for the work, Mr R W Barrett, who was responsible for this project both at UEG and MTD. He also chaired the Project Steering Group.

The original work was prepared by specialist authors (indicated below) working under contract to MTD, and was funded by the following organisations:

- Amoco UK Ltd
- BP Exploration Ltd
- British Gas plc
- Health and Safety Executive
- Phillips Petroleum Co UK Ltd
- Royal Ordnance plc
- Shell UK Exploration and Production Ltd.

During the preparation of the *Guidelines* a delay was imposed which enabled new material, including the implications of recent legislation, to be taken into account. The whole document was reviewed and revised as appropriate during this interregnum; the cost of this additional work was shared by HSE and MTD.

A Steering Group comprising representatives of the sponsors, the specialist authors and MTD provided a forum for discussion during the project. Its membership has been:

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1. Introduction

Explosives always have to be used with great care, but additional safety precautions are required when explosive operations take place under water. Using explosives under water – whether for a large drilling and blasting operation or for small single charges – presents special challenges.

For the first time all the operational details that have to be considered are collected together here in one volume to provide *Guidelines for the Safe Use of Explosives Under Water.* The *Guidelines* cover features that apply to all operations with explosives, such as types of explosives and ways of firing them, transport, storage and the legislation with which operations must comply. Additional factors associated in particular with underwater use include:

- the certainty of a wet environment
- probable transport by or over the sea
- weather conditions
- the remoteness of some operational locations
- the collateral effects of underwater explosions
- possible deployment by divers or ROVs
- transmission of pressure waves through water (which is particularly problematic in shallow water where multipath effects make predictions difficult).

The purpose of the *Guidelines* is to provide the specialist guidance needed when explosives are used in support of underwater operations. They cover all the factors that have to be considered when planning and mobilising an operation, be it offshore, inshore or inland. The advice contained in this document is generally international in its scope, but the legislative requirements (such as those relating to packaging, classification, labelling, transport and storage) are framed specifically on UK regulations – although the interpretations made can be extended to operations beyond UK jurisdiction.

The key to success lies in careful planning, and the *Guidelines* begin by detailing all the features that need to be considered in the plan. The chapter on packaging, transport and storage takes into account the changes introduced by recent European legislation. The chapter on operational precautions enlarges on the safety features of the plan, from security during storage to what to do after a misfire. Then follows a section on the types of explosive that are used under water, and the methods used to initiate them.

The information on pressure waves covers the risks to divers and nearby structures in the water, as well as features particular to seismic operations. The chapter on environmental precautions deals with the possible damaging effects of vibrations transmitted through the ground or through the air, and how to measure them. The final chapter details for the first time the treatment to be given by both first aiders and doctors to anyone accidentally exposed to blast injury.

The *Guidelines* are fully supported by references to literature, legislation and codes of practice. There is also a general bibliography.

Produced after lengthy consultation with key practitioners and regulators, the *Guidelines* introduce a rigorous procedure that will help to systematise and enhance the safe use of explosives under water.

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2. Planning, responsibilities and legislation

2.1 PLANNING

2.1.1 Introduction

The planning phase is probably the most important aspect of any project. With full and effective planning, all the operational stages will slot together to ensure satisfactory completion.

Generally speaking, underwater explosives operations can be split into two distinct areas:

- offshore
- inshore (or nearshore) and work in lakes, lochs, inlets, rivers, canals, etc.

Differences between inshore and offshore work as they affect planning are indicated in this chapter but there are many similarities, especially when inshore work is carried out in a geographically remote area with poor or no access by road.

Because each type of job undertaken with explosives under water is completely different, a detailed planning check list to cover every contingency cannot be provided. Experience dictates what should be considered and investigated, although common sense probably contributes more than anything else during the planning phase. If similar work is repeated frequently, the explosives operating company (the explosives contractor) should compile its own check list for that particular type of operation to ensure even minor points are not overlooked. This section is inevitably general in content and is intended to encourage co-operation throughout the contracting chain from client to sub-contractors and to anticipate potential problems before they occur.

Written procedures outlining the proposed operating method should be prepared before any project is mobilised. This will ensure that all parties involved with the job are aware of their functions and the order in which the explosives operations are carried out. It is important that diving and other underwater engineering contractors cross-fertilise ideas with the explosives contractor at the planning stage, and during the operation itself.

The majority of the points raised in this part of these *Guidelines* are detailed later in Chapter 4 'Operational precautions'.

Planning functions *not* dealt with specifically in this chapter include:

- licensing (advice should be sought from HM Explosives Inspectorate on this complex subject)
- storage of explosives (see Chapter 3)
- transportation (see Chapter 3)
- purchasing and supply.

2.1.2 Survey

Before any underwater explosives operations are carried out, the target area should be surveyed and the actual conditions found should be carefully compared with those originally predicted. If possible, a member of staff of the explosives contractor with practical experience should be present during the survey so that any points of particular interest to him can be checked out.

Items which should be considered in any survey are:

- the overall objective of the operation
- safety and environmental effects
- water depth
- tides and currents
- availability of charts, maps and tidal atlases
- meteorological and oceanographic data (eg normal wind direction and strength, wave height, swell, etc)
- geological and environmental conditions
- overburden (if appropriate)
- proximity of any structures
- positions of any submarine cables and pipelines
- MOD prohibited areas or exercise areas (see Admiralty charts and Notices to Mariners)
- drawings or plans of the target area
- a method of marking the target area

- a datum mark as a reference point
- charge emplacement method
- access to the site
- a radio frequency hazard assessment.

For nearshore or inshore operations, additional items to be considered are:

- utility pipelines and cables (gas, electricity, water, etc)
- overhead cables
- proximity of dwellings and inhabitants
- type of beach (rocky, sandy, etc).

2.1.3 Drawings

All drawings and conditions relevant to the task to be carried out with explosives should be made available by the main contractor in sufficient time for the explosives contractor (or sub-contractor) to plan and devise a satisfactory operating method. If the drawings are produced at the last minute, the explosives contractor may not be able to obtain specialist explosives and accessories in large enough quantities at short notice. Drawings should therefore be an integral part of the tender documents.

The explosives contractor should spend time familiarising himself with the drawings to ensure he fully understands the layout of the seabed and the full extent of the explosives operations and objectives.

For salvage operations, the drawings should contain details of where the cuts should be made, the thickness and type of target material and the access available. For breaking rock or trenching, they should contain the relevant dimensional tolerances (eg grade level, spoil size).

Drawings of any structures near the site of explosives operations should also be made available so that any necessary protective measures can be assessed.

2.1.4 Environmental considerations

In all underwater operations, environmental considerations are of major importance. They should not be overlooked or underestimated at the planning phase. Considerations are frequently the same for both inshore and offshore explosives operations but the response may vary depending on a number of factors including:

- water depth
- tidal conditions – range, speed, times of high and low tide
- other currents
- prevailing wind
- weather for time of year
- weather forecasting and availability of forecasts
- local flora and fauna
- fishing rights (eg spawning, running, etc)
- maximum through-water shock permissible
- maximum air shock allowable (if blasting close to the surface)
- airborne shock overpressure
- access to and from shore
- access for floating equipment
- stability of work platform
- local knowledge (from fishermen, sailors, etc)
- river mouth peculiarities (if applicable).

2.1.5 The work platform and its equipment

Based on the survey and a study of the drawings, a decision may be made on the type of floating equipment that is required and can be utilised in the circumstances of a specific job. Compromises may have to be reached due to the site conditions prevailing. There could be inadequate water depth nearshore to allow access by boat, and supply of consumables may be especially difficult in offshore or remote conditions.

Although not exhaustive, the lists below indicate the factors which have to be considered at the planning stage when selecting a work platform for explosives operations. Compromises may have to be reached between what is ideal, what is available and what is workable.

Offshore

For offshore explosives operations:

- *Supply and storage*
  Daily supply is not always possible and therefore sufficient back-up and spares of all critical components should be carried. There should be adequate deck space available for the magazine and handling the explosives. See 'Deck space' below and Sections 3.3.1 and 3.4.
- *Craneage*
  Craneage should be at least sufficient to lift the heaviest component expected. Should craneage not be an integral part of the work platform, any additional craneage should be firmly fixed to the deck to prevent unwanted movement whilst in operation. Any lifting equipment must be fit for purpose and certified with valid test certificates.
- *Fabrication on site*
  Welding and fabrication facilities may be required. Welding work should be phased so as not to affect explosives' storage and use.
- *Mooring and propulsion*
  The most appropriate type of mooring for the work platform for a specific explosives operation should be assessed before work starts. Dynamic positioning (DP) should be considered if it is likely to be necessary to move off location frequently. There may be no alternative to DP in deep water as the time taken to moor could be unacceptably long compared with the time available for the project. However, the possibility of shock wave interference where DP is controlled by acoustic transponders should be considered carefully. Alternative methods, such as taut wire, may be necessary to enable dynamic positioning where this is a potential problem. Consideration should also be given to the advantages of having a self-propelled work platform rather than one that has to be towed by another vessel. If a dumb barge is used, anchor patterns should be worked out to allow it to move off but avoid damage to the anchor chains.
- *Accommodation*
  Accommodation will be required for all personnel on site. Its standard should be commensurate with the size and expected duration of the project.
- *Communications*
  Good communications, internal and external, are an extremely important feature of any project and the requirements should be clearly stated in the operating procedures (see Section 2.1.10). Communications by satellite or telex should be considered for extended projects, particularly in remote areas. On a single vessel or work platform, portable radios may be required to keep personnel continuously aware of progress. To co-ordinate a number of vessels in the immediate work site they should all be able to communicate with each other.
- *Security and access*
  In selecting a suitable work platform, consideration should be given to both the security and access aspects of the explosives supply and storage.

Nearshore

In nearshore operations, the factors affecting the choice of work platform differ depending on the type of operation being carried out:

- *Draught of vessel*
  The draughts of the vessels available may dictate which ones can be used and which cannot. Draught may also govern whether a vessel can have access to the complete site to be worked and to local harbours.
- *Storage of explosives*
  Generally speaking, smaller vessels are used nearshore or inshore than offshore and the safe storage of explosives on board may present a problem. Security of the explosives outside working hours may be difficult to ensure and it may have to be discussed with the local authorities (eg regional councils and police) and if necessary with the Explosives Inspectorate of the Health and Safety Executive.
- *Communications*
  As in offshore operations, effective communications are essential to maintain safe and steady progress throughout a project. The most important channel of communications may be from the shore to the work platform.
- *Supply*
  Supply of explosives can be a problem in nearshore operations when it is not possible to store all the explosives required for a project on the work platform. It may be necessary to

establish a licensed storage space on the beach together with a routine means of transporting explosives to the work platform.

- *Deck space*
  Whilst it is accepted that deck space is at a premium on a work platform, it is essential that a specific area be designated for the preparation of explosives. See also Section 4.5.1. In deciding upon the location of this area, the following points should be taken into consideration:
  - proximity to the explosives magazine
  - ease of access for personnel involved
  - proximity to the deployment area
  - its ability to be clearly marked.

  As far as is possible and practicable, the preparation area should be:
  - remote from any accommodation areas
  - remote from emergency utilities, such as power generation
  - remote from main propulsion and control.

  When smaller vessels are used as a work platform, deck space may be inadequate for storage and operations, and planning of the project should take this into account.
- *Mooring*
  Smaller work platforms will not have the advantages of dynamic positioning or even self-propulsion. Adequate mooring facilities (eg winches, anchors, cable lengths, etc) will therefore be necessary to manoeuvre the platform around the work site.

2.1.6 Personnel

At the planning stage, the number and organisational structure of the personnel working at the site should be specified.

Only adequately trained and experienced personnel should be given positions of responsibility by explosives contractors, and appropriate records should be kept by all personnel and employers. Some training courses are available for explosives personnel and the Institute of Explosives Engineers provides a central endorsement scheme. Advice should be sought from the Institute in the first instance. CVs and valid log books serve as a guide to experience and competence (and the Institute of Explosives Engineers has produced a log book format for this purpose). Training courses alone do not fully prepare technicians or engineers for working with explosives under water. Experience therefore is generally only gained from working on site with a specialist explosives contractor. Log books can be used to demonstrate that an individual has actual experience of a particular type of job or that his overall experience should be sufficient to enable him to approach a new procedure safely. See Appendix 4 'Training' for more details.

The number of explosives personnel required on a project will be totally dependent on the type of job and the length of shifts worked. To avoid accidents resulting from fatigue it is recommended that they do not work shifts longer than 12 hours. All personnel should be medically fit for the job and a current medical certificate will be required for offshore operations.

The explosives contractor should satisfy himself that adequately trained and equipped first aid personnel will be available on site.

2.1.7 Explosives

It is of the utmost importance to select the right explosive for a specific operation – one that will function correctly, do the job required safely and withstand the environmental conditions. Where necessary, the explosives contractor should consult with explosives manufacturers before making a selection. See Chapter 5 'Types of explosives and initiation'.

The explosives contractor should draw up a short-list of explosives suitable for the project being planned (eg breaking rock, cutting steel, etc) and ensure that the one chosen is suitable for underwater use. Factors affecting explosives under water are:

- *Water resistance*
  Many explosives only have a limited resistance to water and the one that may be first choice for use on land may be unsuitable for use under water. This may either be because of the explosive itself and/or its containment.
- *Hydrostatic pressure*
  Some explosives become desensitised under hydrostatic pressure, again limiting the choice of the most suitable explosive under water.

- *Method of initiation*
  The method of initiation should be powerful enough to ensure reliable and safe detonation of the explosive selected for the task.
- *Toxicity*
  The explosive chosen should, if possible, be non-toxic to the operators and to the environment in which the operation is being conducted. If there are risks from the explosives selected, all necessary safety measures should be taken for the protection of all personnel and the environment (eg rubber gloves should be worn when handling nitroglycerine-sensitised explosives).

A log book should be provided to record all movements of explosives and accessories. The log should also contain information on all explosives used, where placed, how initiated, any misfires and the action taken (see Chapter 4 'Operational precautions').

It should be remembered that large quantities of specialist explosives may not be available at short notice. They should be ordered well in advance as they may have to be specially manufactured.

2.1.8 Accessories

Accessories include all components directly necessary for firing an explosive round. Included in this group are:

- detonating cords
- detonators
- firing cable or lines
- blasting machine/exploder
- underwater connectors
- rope, tape, etc
- circuit tester.

The selection of accessories is much like the selection of explosives in that they should be suitable to operate in the anticipated environment. In particular, the ability to ensure watertight and pressure-tight electrical connections is of the utmost importance.

Details of all these items are covered in Chapters 4 and 5 of these *Guidelines*.

A contingency supply of accessories should always be carried to minimise operational delays due to unforeseen changes in circumstances or procedures. Replacements may be ready on site or may be stored at a main base, in which case the method of transporting them to the work site should be pre-planned.

2.1.9 Logistics and re-supply

Logistics of supply and re-supply are an essential planning consideration. If only one mobilisation is possible or has been allowed for, a detailed list of all equipment, explosives and accessories needed should be produced long before work starts on site to ensure that everything arrives on time. A large project with one mobilisation will require extensive deck or storage space on the work platform.

In planning an operation involving transport of explosives by sea, account should be taken of local restrictions applicable to port or harbour facilities. Explosives can only be loaded or unloaded at licensed berths and it is essential that 24 hours notice of intended movements is given to the harbour master. This requirement covers vessels returning to port as well as leaving.

UK regulations relevant to the transportation of explosives are detailed in Chapter 3 'Transport and storage of explosives'.

2.1.10 Safety procedures

In all operations with explosives, safety is of paramount importance because any lapse of concentration or acceptance of short cuts to save time could prove fatal. The risks are particularly high when non-specialists (eg divers and ROV operators) are working with the explosives technicians and engineers.

Written safety procedures are therefore essential, so that all personnel are aware of the inherent dangers of the explosives being used and what to do in the event of an accident or incident. Details of the subjects to be covered in the safety procedures are to be found in Chapter 4. As a minimum the document should cover:

- personnel and their responsibilities
- briefings

- handling of explosives
- stand-off distances and their enforcement
- fire safety and procedures
- posting of sentries (nearshore operations)
- communications network
- possible radio frequency hazards
- firing timetable, signals and procedures
- 'all clear' signal
- misfire procedures
- disposal of unused explosives
- designation of work site
- designation of explosives preparation area
- positioning of warning signs
- provision of emergency medical facilities.

A procedure for checking that first aid boxes are available on site and their contents checked prior to each operation should be established by the explosives contractor.

The distance from trained medical help and the methods of transport to be used if hospitalisation is necessary should be considered during the planning stage.

2.1.11 Contingency plans

At the planning stage, the only reasonable contingency measures that can be taken are to ensure that adequate supplies of explosives and accessories are available should the working method require modification. Such modifications could be:

- alternative charge design
- alternative hole pattern or size
- alternative initiating method
- use of different explosives
- re-supply of explosives
- alternative approach.

During the planning stage of each operation, critical elements should be identified to form a contingency plan. This will enable any remedial action to be implemented with minimum delay at the work site.

2.1.12 Insurance

All explosives contractors should carry the statutory insurances required for employers' liability (workers' compensation) and motor vehicles.

The main contract or sub-contract will often specify the type and level of insurance cover required but, in any event, it is necessary for the explosives contractor to discuss with the client the insurance requirements specific to each project. Pertinent insurances include third party, public liability, contractor's all risks, professional indemnity and consequential loss. It is recommended that each party should confirm with their respective insurance brokers that all agreed insurances are complied with.

Work should not proceed unless all the parties involved are satisfied that appropriate insurance cover is in force and the cover notes or schedules available for inspection.

2.1.13 Provision of information

During the planning stage, the explosives contractor may be required to provide information to and comply with the requirements of various bodies or authorities in order for the operation to proceed. Typically these are:

- the police
- local authorities (including Environmental Health Department)
- Health and Safety Executive
- Department of Transport
- coastguard
- harbourmasters
- Ministry of Defence (MOD)
- insurance companies or their agents
- utilities (eg water, gas, electricity, telecommunications)

- certifying authorities
- local airports.

In any event, the client or the client's representative should be made aware of the arrangements relating to any of the above.

2.2 RESPONSIBILITIES

It is important to establish responsibilities during the planning stage of each operation, and it is important that they are accepted by *all* concerned. Everyone should be aware of the limits of their responsibility and authority and of any changes to these limits as they arise.

Chain of responsibility

A chain of responsibility should be established and incorporated within the written procedures so that all concerned with an operation know who is in charge of which aspects. The person in charge of each aspect of the operation and the links between each discipline involved should be established.

Firing of explosives

Procedures for firing explosives should be fully understood by all concerned. Only the supervising explosives engineer on site can give the final command to fire. He alone has the final responsibility of deciding whether the charge should be fired. However, the decision to fire may be over-ruled by the offshore installation manager or the captain of the vessel from which the explosives operations are being controlled.

Before charges are placed, the supervising explosives engineer should ensure that the personnel who will be placing the charges are adequately briefed on what is expected of them. This is particularly the case for divers who will be working in limited visibility, in dangerous areas around broken steel, etc and for divers in saturation who are not party to other briefings going on.

On large projects, communication between all disciplines involved is extremely important and briefings are only one of the methods to be employed.

2.3 LEGISLATION

It is outside the scope of these *Guidelines* to attempt to interpret in detail the legislation relevant to the use of explosives under water and this section simply provides an overview and outlines the way in which the legislation is enforced. A selected list of the principal legal provisions and associated guidance related to the use of explosives is to be found in the 'Bibliography'. Many other legal provisions making no direct reference to the use of explosives may also apply – dealing for example with lifting operations, working places, use of electricity and many other common hazards at work that could be present in addition to the risks from the use of the explosives themselves.

All legislative aspects of using explosives in underwater operations should be understood and complied with. It is vitally important that all applicable licences and/or permits are either available or acquired well in advance of a project. Failure to comply with legislation can cause unacceptable delays and disruption to the project, and result in penalties. If in doubt, consult the Health and Safety Executive (HSE) for guidance.

The principal legislation relevant to the manufacture, transport, licensing and storage of explosives is contained in the *Explosives Act 1875*(2.1) as amended by the *Explosives Act 1923*(2.2), and in Orders in Council and Orders of the Secretary of State made under these Acts. The legislation is generally enforced by HM Explosives Inspectorate of the Health and Safety Executive. These Acts remain in force but have been frequently amended by subsequent legislation. The principal relevant instruments are described in Chapter 3.

Underwater and offshore operations

Under the *Health and Safety at Work etc. Act 1974* (HSW Act)(2.3), pre-existing enactments have been progressively replaced by new regulations and approved codes of practice. The *HSW Act* applies to underwater operations in inland and inshore waters. By an order made in 1977, it was extended to specified activities in territorial waters and designated areas outside Great Britain, including offshore installations, pipelines, mines, construction-related activity and diving operations. A new version of this order, *The Health and Safety at Work etc Act 1974 (Application outside Great Britain) Order 1995*(2.4) came into force in March 1995.

The administration of health and safety legislation offshore was substantially reorganised following the recommendations of Lord Cullen's inquiry into the Piper Alpha disaster of 1988. A new Offshore Safety Division was set up and is now part of HSE which also houses the Diving Inspectorate who regulate underwater work inland, inshore and offshore. HSE's offshore and inshore diving interests form part of the Offshore Safety Division and are co-ordinated by HSE's Chief Inspector of Diving and his National Responsibility Team (NRT) based in London. New diving regulations are being prepared to replace *The Diving Operations at Work Regulations 1981*(2.5) and are expected to come into force in 1997.

Diving operations not related to oil and gas production and which take place from UK ships outside territorial waters are the subject of *The Merchant Shipping (Diving Operations) Regulations 1975*(2.6), enforced by the Marine Safety Agency of the Department of Transport.

HSE's Offshore Safety Division introduced legislation in 1992 requiring a safety case to be made and maintained for all major offshore operations. It makes no specific reference to either the storage or use of explosives, but an operator is required to show that the design and operation of an installation, its plant and any pipelines connected to it are such that the risks from a major accident are at the lowest level that is reasonably practicable (ALARP). A safety case is required for the abandonment of installations, which could involve underwater explosive cutting.

Explosives

Chapter 3 of these *Guidelines* describes the legislation covering the handling, storage and transport of explosives. The legislation, and associated approved codes of practice, are reviewed from time to time and it is wise to check that the legislation described in these *Guidelines* is still current before commencing any work with explosives.

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3. Transport and storage of explosives

This chapter outlines current rules, regulations, considerations and responsibilities involved in the movement, storage and security of explosives in routine transit in the United Kingdom and illustrates the environmental and operational considerations specific to offshore use.

The interpretations discussed here are to help a non-practitioner have an understanding and appreciation of the difficulties in transporting and storing explosives. The terminology used may therefore differ from that used in the regulations, and guidance should be sought if required from the appropriate enforcing authority. The process of controlling the safe use of explosives with respect to the regulatory requirements is not straightforward.

Table 3.1 is a summary of the main UK legislation. It shows how it interlinks to form an integrated regulatory system and identifies the enforcing authorities.

Table 3.1 *UK regulatory requirements for the safe use of explosives*

Activity	Applicable regulations and acts	Key requirements	Duty holders	Relevant authorities
Packaging	*Packaging of Explosives for Carriage Regulations 1991* (PEC)	Require packages to be tested and certified and to carry a UN mark. Lay down requirements for the design, construction and maintenance of packagings. Testing, certification and allocation of UN mark done by PIRA International on behalf of the Department of Transport.	Carriers Consignors	Enforcement: HSE Issue of certificates: Department of Transport
Classification and labelling	*Classification and Labelling of Explosives Regulations 1983* (CLER)	Require explosives to be classified and correctly labelled. Classification of commercial explosives done by HSE; classification of military explosives by Ministry of Defence. Proof of classification of commercial explosives is given on a Competent Authority classification document (CA document) issued by HSE.	Those keeping, conveying or supplying the explosives	Enforcement: HSE Issue of classification documents: HSE for civil explosives and Ministry of Defence for military explosives
Authorisation	Section 40(9) of the *Explosives Act 1875* as modified by Regulation 12 of the *Placing on the Market and Supervision of Transfers of Explosives Regulations 1993* (POMSTER)	Applies to all explosives except gunpowder. Authorisation is done by HSE, usually at the same time as classification. HSE has issued conditions for the authorisation of explosives.	Supplier of explosives	Enforcement: HSE Issue of authorisations: HSE
Conformity attestation	*POMSTER* (see above)	Certain types of explosives are subject to the requirements of *POMSTER* and are subject to attestation by Notified Bodies.	Person placing explosive on the market	Enforcement: HSE Issue of CE mark: Any Notified Body
Security	*Control of Explosives Regulations 1991* (COER)	Require the possession of an explosives certificate, keeping records and reporting losses.	Person acquiring and keeping explosives	Enforcement: HSE and police Issue of certificates: Police
	POMSTER Section 23 of *Explosives Act 1875*	Require a Recipient Competent Authority (RCA) issued by HSE	Person acquiring explosives	Enforcement: HSE Issue of RCA: HSE
	Explosives Act 1875	Requires occupiers of factories, magazines, stores and registered premises to take all due precautions for preventing unauthorised access. HSE, in discussion with police, local authorities and other bodies, has produced a generally available position paper on what constitutes 'all due precautions'.	Person manufacturing or keeping explosives	Enforcement: HSE at licensed factories and magazines Local authorities at licensed stores and registered premises
Transport by road	*Road Traffic (Carriage of Explosives) Regulations 1989* (CER)	Require standards of transport, including choice of vehicle, safety and security, mixed loads, marking of vehicles, information to be carried, duration of carriage and action in emergencies or accidents. Supported by guidance and an approved code of practice.	Vehicle operators Consignors	Enforcement: HSE

(continued opposite)

Activity	Applicable regulations and acts	Key requirements	Duty holders	Relevant authorities
Transport by road (cont)	*Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Loads) Regulations 1992* (DTR)	Require standards of driver training, taking of examination and issue of Vocational Training Certificate. Department of Transport deals with certification aspect and approval of trainers.	Anyone carrying dangerous goods Drivers	Enforcement: HSE with respect to explosives
Transport by sea	*Dangerous Substances in Harbour Areas Regulations 1987* (DSHAR)	Require controls for movement of explosives through harbours. Includes licensing of berths by HSE.	Primarily: Operator of road vehicle Master of vessel Harbour authority Berth operator Harbour/berth explosives security officers	Enforcement: HSE
	Merchant Shipping (Dangerous Goods and Marine Pollution) Regulations 1990 (MSR)			Enforcement: Marine Safety Agency
Transport by air	*Air Navigation (Dangerous Goods) Regulations 1994* (ANDG) ICAO *Technical Instructions*	Draw on ICAO *Technical Instructions* to require accompanying documentation, loading, provision of information and responsibilities.	Shippers Aircraft operators	Enforcement: Civil Aviation Authority
Keeping	*Explosives Act 1875* (EA 1875)	Four types of storage available. The local authority options (see last column) tend to be more straightforward. HSE options are subject to procedures laid down in *EA 1875* and can be lengthy processes. HSE has issued guidance on the procedures for obtaining their licences.	Anyone keeping or manufacturing explosives	Licensed magazine or factory: HSE Licensed store or registered premises: Local authorities

3.1 PACKAGING, CLASSIFICATION AND LABELLING

Before an explosive can be transported, sold or used it should be classified and authorised by the Health and Safety Executive (HSE) according to its type and characteristics and by the hazards it represents. Once classified, the explosive is given an identification number under the United Nations system (see below) and should be labelled accordingly and stored in conditions appropriate to its needs. The storage conditions should satisfy the requirements of the explosive, protect it from outside influence and protect the area immediately outside the store from the effects of the explosive should it react to destabilising agencies. Specific security arrangements may also have to be met as determined by the local police and HSE.

3.1.1 Packaging

The packaging of explosives is governed by *The Packaging of Explosives for Carriage Regulations 1991* (PEC)(3.1) which should be consulted for detailed requirements. An explosive should be packaged for transport in such a way that it does not represent a hazard to those handling it. The package should protect the contents against shock, environmental stresses and any other influences that may damage the explosive or cause it to deteriorate or explode prematurely. Package types vary according to the mode of transportation to be used and the degree of rough handling to which the package may be subjected. Explosives packed into metal containers as part of their fabrication into charges (eg plastic explosives to be used as shaped charges) are *not* ready for transportation; they should be packed into further suitable boxes.

In addition, the package should clearly describe the content by:

- type
- identification number and symbols
- net explosive content (as distinct from the gross weight of the package).

3.1.2 Classification and labelling

The Classification and Labelling of Explosives Regulations 1983(CLER)(3.2, 3.3) represents the first stage in a series of Regulations designed to update the *Explosives Act 1875*(3.4) and the legislation made under it (comprising 80 Orders in Council, Orders of the Secretary of State and Regulations). The new Regulations are based on the objectives and philosophy of the Robens Report, *Safety and Health at Work*(3.5) and the *Health and Safety at Work etc Act 1974*(3.6).

CLER uses the almost universally accepted United Nations publication, *Transport of Dangerous Goods*(3.7), popularly known as the *'Orange Book'*. Its recommendations were originally prepared in 1957 but have subsequently been updated and revised. The recommendations were based largely on existing international regulations. They cover:

- the classification and definition of classes
- listing of the principal dangerous goods
- hazard categories
- packing
- marking
- labelling
- placarding
- shipping documents.

They do not apply to dangerous goods in bulk (eg hydrocarbons) and they do not attempt to override national or international regulations governing the various modes of transport. They do provide a broad, flexible framework into which most national regulations can be fitted.

By adopting the principles of the *Orange Book*, international uniformity in classification will eventually evolve and a smooth transition will be achieved to a universal system of managing the transport of dangerous goods.

3.2 TRANSPORT

3.2.1 General

The system of regulatory control of transport of explosives in the UK seeks to reduce danger through a number of integrated elements:

- *The Road Traffic (Carriage of Explosives) Regulations 1989* (CER)(3.8) place requirements on the operational aspects of the transport operation
- *The Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Goods) Regulations 1992* (DTR)(3.9) require training of drivers
- *The Classification and Labelling of Explosives Regulations 1983* (CLER)(3.2) ensure that the explosives are safe for carriage and have an identified hazard
- *The Placing on the Market and Supervision of Transfers of Explosives Regulations 1993* (POMSTER)(3.10) have a role which is described below.

The Placing on the Market and Supervision of Transfers of Explosives Regulations 1993 (POMSTER)(3.10) are intended to ensure the safety and standards of explosives being transferred, particularly between member states of the European Union. Compliance is shown by the 'CE' mark and accompanying transfer documentation. All explosives that enter the UK are covered by POMSTER. A new division of HSE, the Explosives Notified Body (ENB) based in Buxton, was set up in 1995 to assess and certify explosives and approve the affixation of CE marks.

POMSTER was introduced in the UK to implement EEC Directive 93/15/EEC (*The Placing on the Market of Explosives for Civil Use Directive*). The intention of the Directive is mainly to ensure uniformity of product standards between member states, but the UK regulations also contain a schedule of essential safety requirements for the design, manufacture and supply of explosives to minimise the risks to people, property and the environment. Included in the general safety information that must be considered is the requirement for resistance of an explosive to the influence of water where it is intended to be kept or used in humid or wet conditions and where its safety or reliability may be adversely affected by water. Extremes of temperature also have to be taken into account. Although *POMSTER* came into force at the beginning of 1995, prior requirements provide transitional arrangements until 1 January 2003 when all new requirements will become mandatory.

POMSTER applies to the physical movement of explosives to any place in Great Britain or its offshore area, and supplements the security controls given in *The Control of Explosives Regulations 1991*(COER)(3.11). *COER* is mainly aimed to ensure that explosives are handled responsibly and do not fall into the wrong hands. Anyone keeping certain explosives must have an Explosives Certificate issued by the police, and a person must be appointed to be responsible for security at licensed explosives magazines.

POMSTER affects transport operators, shipping agents and other carriers, as well as the consignors and consignees. It also covers anyone carrying their own explosives. It applies to nearly all Class 1 explosives as classified in *CLER*(3.2). Specific rules apply to different means of transport as detailed below.

Documentation

Transfer documents are issued by HSE, although anyone with a valid *COER*(3.11) Explosives Certificate receives one automatically without having to apply. Firms operating in the offshore industry who acquire explosives by direct delivery from outside mainland Great Britain need a transfer document even though they are not required to have an Explosives Certificate. There are two types of transfer document. For transfer through countries with normal security arrangements, a period transfer document is sufficient, normally valid for up to three years. In some EU member states, such as Spain and Ireland, special security arrangements apply and prior approval is required for every movement of explosives. This situation is continually under review and liable to change.

CEN (the European Union and EFTA standards organisation based in Brussels) has announced its intention to produce standardisation in support of the Explosives for Civil Uses Directive, which will therefore be relevant to *POMSTER*. The mandate defining the programme of work was published in the April 1995 issue of the Bulletin of the European Standards Organisation. The work falls into five categories: explosives for civil uses, high explosives, detonating cords and safety fuses, detonators and relays, and propellants. The section on explosives for civil uses cover terms and definitions, categories, and specifications for labelling and information to be provided. The other sections cover requirements and test methods. This is a considerable body of work.

3.2.2 Transport by road

The Road Traffic (Carriage of Explosives) Regulations 1989 (CER)(3.8) and the accompanying *Approved Code of Practice*(3.12) give direction, amongst other things, on:

- the correctness of packaging and labelling for road transportation of explosives
- weight limits
- construction, modification, marking and control of vehicles
- training of vehicle crews
- emergency procedures to be followed after breakdown, fire, collision, etc.

Documentation

Where appropriate, the driver of the vehicle must carry written information covering the Division and Compatibility Group of classified explosives, their mass, the consignor and consignee, and any other information necessary on the dangers involved and the actions to be taken in an emergency.

3.2.3 Transport by sea

Guidance on the loading and transportation of explosives in ships is contained in a series of volumes entitled *International Maritime Dangerous Goods Code*(3.13), published by the International Maritime Organisation (IMO). The volumes cover all aspects of dangerous dry goods carried on ships, including explosives. A separate book covers liquid cargoes.

The *IMDG Code* is very similar in format to the *Orange Book*(3.7), and in many respects the two are complementary. It advises on how and where to stow various commodities on ships and warns of the dangers specific to shipping. It retains the use of the UN number (see Section 3.1 above) and correct shipping name and category as recommended by the *Orange Book* for general identification of dangerous cargoes, but converts the recommendations into actual practical stowage requirements. It also implements safety and pollution prevention requirements based on IMO conventions.

The Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations 1990(3.14) detail the responsibilities of shipowners and their crews when involved in the handling of dangerous goods and generally implement the requirements of the *IMDG Code.*

Documentation

The *Code* further advises that explosive substances should be delivered to the dock covered by a correctly presented 'Dangerous Goods Note', which gives specific information on the content of a package or group of packages. The document advises the ship's master of the UN number, explosives weight, packing details, port of loading, port of discharge and other pertinent details. The document should be signed clearly by the shipper's representative who makes a formal declaration of the correctness of the information and is personally liable for any incorrect statement. It also includes a separate declaration made by the packer, to ensure that dangerous goods have been correctly loaded onto a vehicle or freight container.

Loading and off-loading

Quantities of explosives exceeding 1 tonne in weight can only be loaded or off-loaded at licensed ports or, in some ports, at licensed berths. Smaller amounts can be handled at unlicensed ports.

The Dangerous Substances in Harbour Areas Regulations 1987(3.15) control the loading and off-loading of explosives and other dangerous goods in UK harbours. Part IX is specific to explosives. The *Regulations* direct the harbour master in his role of controlling the movement of explosives and vessels carrying explosives in all parts of the harbour. They explain the marking of packages again, the meaning of explosives terms, and the scope of application. They require that prior warning should be given of the intention to deliver explosives to the harbour for handling. An interpretation of the *Regulations* has been prepared by HSE, entitled *Approved Code of Practice – Dangerous Substances in Harbour Areas*(3.16).

3.2.4 Transport by air

In the United Kingdom, legislation concerning the carriage of explosives by air is contained in *The Air Navigation (Dangerous Goods) Regulations 1994* (ANDG)(3.17). Among other things, these require that dangerous goods can only be carried in accordance with the International Civil Aviation Organization's *Technical Instructions for the Safe Transport of Dangerous Goods by Air*(3.18). The 'competent authority' in the UK is the Civil Aviation Authority, specifically its Dangerous Goods Office.

Although the *Technical Instructions* is the document referred to in *ANDG*, operators in practice use a 'field' document – the International Air Transport Association's *Dangerous Goods Regulations*(3.19). The two documents are largely compatible and the *IATA Regulations* recognise that the *Technical Instructions* contain the 'sole authentic legal source material'. In the UK, it is acceptable to use the *IATA Regulations* in lieu of the *Technical Instructions*, but it is the responsibility of shippers, agents, operators, etc to ensure that if they choose to use the *IATA Regulations* they meet their legal responsibilities as set down in the *Technical Instructions*.

The *Technical Instructions*, based on the UN *Orange Book*(3.7), contain a comprehensive set of requirements covering all aspects of carrying explosives by air including the 'E' packing methods, which are reproduced as packing instructions. However, explosives cannot simply be packed in accordance with a packing instruction; they must be packed in the manner in which their original classification by a competent authority was obtained. Failure to do so may alter the classification and consequently the hazard of the explosive.

Most explosives are forbidden for carriage by air, although those in Division 1.4S may be carried on both passenger and cargo aircraft. A few others in Divisions 1.4 and 1.3 may also be carried, but on cargo aircraft only. In certain circumstances, the Civil Aviation Authority may grant an exemption from the *Regulations* to permit the carriage of explosives normally forbidden for air transport. The exemption is granted to the aircraft operator and contains specific conditions under which the explosives may be transported. Depending on the quantity and type of explosives involved, these will include the airfield and the specific position on that airfield where the explosives may be loaded and unloaded. A potential shipper of explosives by air should first contact the operator who will in turn approach the Civil Aviation Authority.

Documentation

ANDG(3.17) require that each consignment of explosives is accompanied by a dangerous goods transport document. Whilst there are no legal requirements for the appearance of this form, IATA produce an equivalent 'Shipper's Declaration' which is commonly used. It certifies that the explosives have been declared, classified, packed, marked and labelled in accordance with the requirements, and must be signed by a suitably trained person.

The aircraft operator has a legal responsibility to carry out a comprehensive check of each consignment to ensure that it meets the requirements. Any errors in the preparation of the package or documentation will result in the consignment being rejected.

3.3 STORAGE OF EXPLOSIVES

3.3.1 Storage

Explosives may only be stored in a:

- licensed magazine
- licensed factory
- licensed store
- registered premises.

Application to erect and use any kind of store for explosives should be made to the appropriate licensing authority. This is the local authority (county council or London borough council in England and Wales or the regional council in Scotland) for a store for mixed explosives when the quantity to be stored does not exceed 1815 kg, or the Health and Safety Executive for an explosives magazine for a larger quantity.

Application is often a protracted process (particularly for an explosives magazine licence – see *Memorandum for the Guidance of Applicants for a Licence for an Explosives Factory or Explosives Magazine*(3.20)) as many criteria must be met and the requirements of many interested parties satisfied. The local police, local authority, local planning authority, local landowners, etc should all be approached through the correct channels and each group should be satisfied as to the function, security and intrinsic safety of the store and its contents.

The siting of the building relative to other structures and surface and sub-surface services (such as water mains, electricity cables, pylons, etc) should all be considered and its proximity will dictate its maximum licensed weight limit.

HM Inspectorate of Explosives has evolved practical guidance to set explosives weight limits and safety distances and to advise on protective fences, earth banks, warning notices and fire precautions. They have also made recommendations for the security of the building, its minimum construction criteria, lightning conductors and bonding against static electricity. Their guidance may be found in the *Guide to the Explosives Act 1875*(3.21), *Storage of Explosives: Security Arrangements*(3.22) and *Security of Explosives Stores and Registered Premises*(3.23).

3.3.2 Site preparation of explosives

A licensed explosives store or magazine may only be used for storing explosives. A box of explosives in a store should not be opened and its contents removed or otherwise handled; the box should be moved to another location for any handling operations. For example, the task of inserting explosives into specialist casings or devices should be performed either in an explosives factory or *immediately* before use after the explosives have been taken from the store or magazine. ('Factory' in this context means a building in which an explosive is modified, re-shaped and/or repackaged.)

3.4 TRANSPORT AND STORAGE OFFSHORE

It is essential that the storage and transportation of explosives and accessories in the potentially dangerous environment of an offshore oil and gas platform, mobile drilling unit, dive support vessel or other offshore installation are carefully controlled, supervised, phased and co-ordinated. Safety concerns must be paramount on a work platform which is so crowded with plant, equipment and materials that the safety distances laid down by HM Explosives Inspectorate for land-based operations cannot be met.

Explosives transported to an offshore installation or other offshore work platform by sea usually arrive on a supply vessel. They may be transferred in approved boxes housed in a normal (but properly placarded – see Section 3.1) offshore container for ease of handling and security or they may arrive in a specially constructed portable magazine painted and placarded in accordance with the regulations also described in Section 3.1.

The siting and security of any explosives store on an offshore installation on the UKCS will be detailed in the safety case submitted to HSE by the installation's owner/operator. In addition, the storage and use of explosives will have been considered in the assessment required by *The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations* 1995 (PFEER)(3.24). Any portable magazine should be placed on board at a point considered safe for that purpose by the offshore installation manager. He should bear in mind other hazards on board, the requirements of the safety case, the *PFEER* assessment and the advice of the supervising explosives engineer. Particular attention will need to be given to ensuring escape routes are not affected.

The storage of explosives on a vessel not within the scope of the safety case regulations or *PFEER* requires consultation between the captain of the vessel and the explosives contractor. Consideration needs to be given to all the hazards likely to be encountered that may have an adverse effect on the safety and security of the explosives. Wherever possible, explosives should be stored as far as possible from any accommodation areas and should not hinder any emergency means of escape or facilities for firefighting.

All personnel on board should be made aware of the presence and siting of explosives on an installation or vessel.

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4. Operational precautions

4.1 INTRODUCTION

This chapter is a guide to the actual operations involved in the use of explosives under water. It is intended to establish a safe working environment at a practical level. Some of the points made are not relevant to all types of operation and, conversely, it is impossible to visualise all possible situations. Common sense should always prevail.

It must be stressed that the guidance here is intended to be used by experienced and competent explosives engineers as a supplement to their specialist knowledge. It is not intended to be a 'beginners guide' to the use of explosives under water.

4.2 SECURITY AND SAFETY OF EXPLOSIVES

4.2.1 Security

It is important to ensure that all containers of explosive materials are made fast to the work platform to prevent unwanted movement, or locked in an approved or licensed store which in turn is made fast and electrically bonded (earthed) to the work platform.

Only the amount of explosive required for a particular shot or for each charge should be removed from the magazine at one time. The magazine should be kept locked at all other times.

All explosives and accessories should be logged and checked from the point of despatch through to delivery to the magazine and to final use, so that at any time the amounts that have been used and that are in the magazine are known precisely. During the course of prolonged site operations the amounts should be double checked at regular intervals.

One person, usually the supervising explosives engineer, should be in overall charge of all explosive materials,

4.2.2 Fire safety and procedures

Any work which may generate heat or sparks (hot work) should not take place near explosives or accessories. All explosives and accessories should be returned to the magazine and locked away if any such work is necessary on deck.

Explosives should be kept away from all exposed electrical circuitry especially when connections/disconnections are made and there is a risk of sparks and arcing. The actual distance should be a matter of practical judgement.

At the start of a project, the supervising explosives engineer in charge should discuss the consequences of fire with all personnel involved, especially the safety and firefighting team(s) of the work platform. Consideration should be given to the type and purpose of work platform, likely products in the vicinity, any other work likely to be in progress on board and any flammable materials being used or processed. The supervising explosives engineer should check the firefighting facilities, procedures and equipment available for a specific project; he will have to assess the effects of the compositions of the explosives and accessories being used and the confinement and proximity, etc.

A chain of command for firefighting should be established for any project and agreed before starting work.

Normally, if fire breaks out on board, the area should be evacuated. If a fire on a floating vessel or fixed platform spreads to the explosive material, then evacuation is one possibility, but if the fire can be isolated and dealt with by onboard firefighting equipment, evacuation need not necessarily take place.

In the specific cases of oil and gas exploration or production, it is assumed that normal shutdown procedures will have been initiated immediately upon detection of fire.

4.3 BRIEFINGS

Personnel should be kept to a minimum in the area where explosives are to be handled and deployed, and all personnel using or handling explosives should be adequately trained (see Section 2.1.6) and briefed on what they are expected to do. Regular briefings are essential so that *all* personnel are aware of what is going on and the progress being made. Daily updates should be given to all involved in the operation.

It is important that divers are briefed by the supervising explosives engineer before an operational dive and that they fully understand what they are required to do, the importance of correctly placing the charge, and the basic mechanism by which the result is to be achieved. If the project involves divers in saturation they should be briefed *before* entering the deck compression chamber (DCC) if at all possible but certainly before entering the bell to carry out their work. Any explosives project involving saturation facilities will be a substantial one and ample time should be made available to brief the diving team fully.

As a part of any briefing, all personnel should be advised of the stand-off distances to be used and the associated duties of sentries, guard boats, etc when the blast takes place.

4.4 WEATHER, SEABED AND SEA STATE CONSIDERATIONS

The check list below is intended as a guide to the environmental factors that affect explosives operations and which should be addressed before each weather-critical stage starts:

Waves

- Is the work platform sufficiently stable to prepare explosive charges?
- Can subsidiary craft (eg inflatables) be launched and recovered if necessary?
- Is the jib of any crane being used stable enough to ensure that neither the crane nor its payload will be jarred or snatched due to the motion of its parent vessel?
- Can divers work safely on the seabed (eg are they affected by swell)?
- Will explosive charges need additional ballasting or securing because of wave action?
- Can divers be recovered safely after their work is complete?

Wind

- Is the mooring system or dynamic positioning system sufficient for the wind?
- How is wind affecting the attitude of the work platform – which side to deploy from, windward or leeward?
- Is the work platform to be moved after setting the explosive charges, eg against the wind?
- Are accessories and equipment on deck adequately secured?

Seabed

- Is a working frame or platform necessary to hold the charges?
- Is visibility a problem if the seabed is disturbed?
- Is seabed movement (eg movement of sandwaves) liable to disrupt the operation?

Tides and current

- Is the work platform mooring system sufficient for currents and tides?
- If the work platform's attitude is determined by current, is the current likely to change – with the tide for example?
- How will currents affect the explosive charge as it is transported to the seabed?
- How will currents affect the charge on the seabed?
- How will currents affect the firing lines – where will they end up?

General

- Which way will the work platform drift if its mooring or positioning system fails?
- If the weather is deteriorating, can the operation be completed safely or should it be aborted?
- How is the weather affecting other vessels in the area?

If there is reason to believe that the weather is worsening and likely to exceed safe operating parameters, explosives operations should not proceed.

If an electrical storm is imminent, all explosives operations should cease, all explosives and accessories should be returned to store and the earthing of the magazine to the deck of the work platform should be checked.

4.5 PREPARATION

4.5.1 Preparation of charges

It is essential that a specific area be designated for the preparation of explosives and this should be clearly marked. Considerations in the choice of location of the preparation area are given in Section 2.1.5.

Any tools used for preparing charges should be made of non-ferrous and non-sparking materials. Knives can be used to cut detonating cord but preparation should be carried out on a non-metallic surface, preferably wood.

All non-essential personnel should be kept away from the preparation area when explosive charges are being prepared.

If liquid explosives are being prepared or mixed, a copious supply of water should be immediately available for washing any spills overboard. Liquid explosives should not be mixed in an enclosed space.

All explosives work areas should be adequately ventilated and kept clean and tidy.

Warning signs

Warning signs should be posted and ropes should be fixed around the explosives preparation area, to warn people and to advise them to keep away. All signs used should be large, clearly marked, easily understood and immediately visible by the people that they are intended for.

Vessels in the immediate work area, specifically vessels carrying explosives and any vessels acting as guards or sentries, should fly the international sign FLAG 'B' (red flag) to indicate that explosives operations are being conducted. Inshore or inland, red flags and warning signs may be necessary at access roads, particularly in hilly areas, to give the public sufficient warning.

4.5.2 Connections

Detonating cord

Connections in detonating cord should be securely taped with plenty of overlap where joints occur. Ends should be sealed to prevent water entry and to ensure smooth transfer of initiation.

To prevent cut off, care should be taken to avoid sharp bends, kinks and layouts where cord crosses itself or another run. Circuits should preferably be run in a loop so that if cut off does occur at one point during initiation the rest of the round should still fire.

Connections between detonating cord and the charge should be firmly fixed and secured to ensure that misfire does not occur from a pulled-out cord.

Electrical connections

Circuits of electric detonators should be wired in series as this gives greater assurance of an 'all fire' and testing is more positive (see Section 4.7.1). If exploding bridge wire detonators are used, each will normally have its own high voltage module.

It is recommended that all electrical connections under water should be insulated using petroleum-jelly-filled connectors and adhesive tape. Silicone grease should be used for high temperature applications. This should prevent current leakage and unacceptable power loss during firing in large circuits. The taping reduces the risk of connections being disturbed, shorted or broken by external forces from sea currents, etc.

It is recommended that firing lines should be of one continuous length without any joins. If this is not possible, particular attention should be paid to any joining junction. Wires should be joined in such a way that the actual electrical connection is not subjected to any load. Where wires have been joined by twisting together and then doubled, the wire should always be knotted so that the joint suffers no strain. It is a good practice to tape firing lines to soft rope or wire for support. Lead wires should never be pulled where they enter a detonator. This may break the fusehead or, at worst and under certain conditions, initiate the detonator.

4.5.3 Detonators

Generally, detonators are the most sensitive part of any explosive system, not least because they contain primary compositions. They should only be brought out of storage immediately before they are required. They should be handled carefully but firmly with their lead wires kept coiled or twisted wherever possible.

It is important to ensure that the physical connection of the detonator to the charge or detonating cord is both intimate and secure, and that other precautions mentioned in this section are adhered to. Wiring of the electrical firing circuit to the detonator should be completed before the 'ballistic' connection is made, ie before it is brought into contact with the charge and/or detonating cord. Additional protection can be ensured by placing the detonator inside a properly designed steel 'safety loading tube' before connecting the lead wires to the electrical firing circuit.

Detonators and firing lines should be handled and arranged with great care:

- keep all exposed ends of firing lines and detonators shorted (shunted) until immediately before connection
- maintain the insulation of all blasting wires and insulate any connections in them
- use twisted pairs of wires or twin-wire configuration
- keep detonator lead wires together, ie twisted or bunched, immediately prior to making connections
- always run firing lines at a low level along the deck of a work platform
- *use suitable detonators with sufficient output to initiate the explosive train.*

Sufficient current must be introduced into a blasting circuit for initiation, intentional or unintentional. To introduce the current directly, a voltage potential has to be applied to a point in the circuit so that current can flow through it to another point (ie the sequence of events in the normal firing procedure). Unintentional direct introduction can be prevented by maintaining good insulation throughout the circuit. It is very important that the explosives engineer and all members of the project team remain vigilant at all times. They should check the firing line before every deployment and guard against any opportunities for damage, eg from mobile plant, chaffing and heavy footwear. The voltage itself could come from faulty electrical equipment or wiring and arc welding or CP systems.

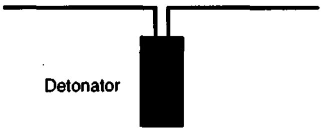
Radio frequency emissions

Radio frequency (RF) emissions are often considered to be potential hazards in explosives operations, capable of indirectly introducing sufficient current in a circuit to fire the detonator. To counter this, radio silence (including hand-held radios) is often insisted upon(4.1), but radio silence itself may well be a hazard because effective communications are a vital part of any explosives operation. Theoretically, sufficient current to fire a detonator can be introduced indirectly by RF fields – but only if the emissions are strong and quite specific conditions are met. There is a great deal of misplaced concern about the hazard presented by RF emissions, and it is regarded by many as a sensitive subject. However, all published work and investigations indicate that there is only an extremely remote likelihood of inducing sufficient current in a blasting circuit to initiate a detonator. Radio frequencies between 0.4 and 1.6 MHz are potentially the most hazardous for RF problems.

Appendix 3 describes a detailed procedure for the assessment of RF hazard.

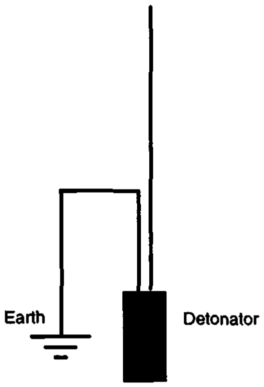
Part of a blasting circuit can behave as an RF pick-up circuit in three basic configurations:

- *Dipole aerial*



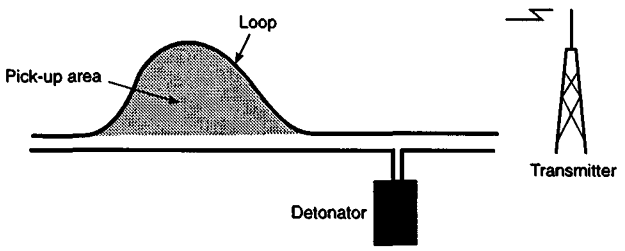
If the length of detonator lead wires in a dipole aerial configuration matches the wavelength of a transmitter of sufficient strength, a voltage may be induced between the ends. Underwater however, attenuation discounts the risk from this hazard.

- *Monopole aerial*



In offshore oil and gas work, a monopole layout is a likely configuration during drilling and wireline operations where, conventionally, an EED (electro-explosive device) is lowered down the hole and connected between the wireline and an earthing ring. The wireline behaves as the monopole aerial. This hazard is recognised in the oil industry and procedures are in place on every rig to deal with it. In any case, it represents a worst case; shielding from the derrick and surrounding structures greatly attenuates any RF signals. Also, explosive initiation systems are now available that can be operated without use of the wireline.

- *Loop aerial*



Part or all of a blasting circuit may inadvertently form a loop aerial. The loop's capacity to pick up RF emissions is proportional to the size of the loop.

Firing lines and/or detonators should be laid out and deployed so they do not model any of these aerial configurations. It is quite possible to arrange any blasting circuit without creating an unnecessarily hazardous situation.

Premature RF-induced detonation may occur:

- *During storage on board the work platform.* Providing all detonators are kept shunted and stored in a proper detonator magazine until required, RF emission is not the primary hazard.
- *During the preparation of charges and firing circuits on the work platform.* RF filters should be incorporated into the circuits as an additional precaution if high levels of RF emission are likely to occur, but they tend to be ineffective at frequencies below 2 MHz. The main causes for concern are high power transmitters operating at relatively low frequencies, from a few 100 kHz to a few MHz. 'Marine band' transmissions (at 400–500 kHz) from service vessels, for example, can present an RF hazard to explosives operations offshore. Special devices, such as EBW or EFI detonators (see Section 5.2.3), could be used in these circumstances. High levels of emissions are only likely to be encountered close to high power transmitters. Arc welding equipment and impressed current anti-corrosion systems, for example, may also be local sources of stray electric currents. As a general principle, the complete firing system should be kept electrically insulated, especially the terminals. Frequent checks should be made on the physical integrity of the insulation of firing lines and equipment. As a general rule, where firing lines cross open decks or other parts of a vessel, they should be kept on the deck and not suspended.
- *Under water.* The attenuation of RF emission is so great under water that the hazard can be discounted in practice. From an electrical hazard point of view, underwater communications present little risk of setting off explosives under water. Only if the terminals of a communications set were to be directly connected to an electric detonator is there a potential hazard. Connections and terminals should be insulated to avoid this possibility.
- *During wireline services involving explosives.* Because detonators are run on a wireline which runs up and down the drilling derrick, it can act as a monopole aerial (see above). At certain frequencies, this can induce sufficient current to cause an ordinary detonator to fire. Detonators have been designed specially for these operations, taking into account the harsh environment encountered down hole, particularly for high temperatures and pressures. For this particular operation, detonators are classified into four categories:

  Category 1 – ordinary electric
  Category 2 – resistorised electric
  Category 3 – resistorised and protection fuse wire
  Category 4 – incorporating an RF filter.

  Within each category there are types that also incorporate fluid-desensitising devices.

  It is strongly recommended that only Category 2, 3 and 4 detonators are used for these wireline operations. The publication *Recommended Practices for Radio Silence when Conducting Wireline Services Involving the Use of Explosives*(4.1) gives considerable guidance and detail of these specialised procedures.

See also *BS 6657: 1986*(4.2) for guidance on the prevention of inadvertent RF initiation of detonators.

The higher the energy required to initiate electric detonators the less likely they are to fire through stray or induced currents. Unless large rounds are to be fired, high energy (ie low sensitivity) detonators should be used offshore. Typical firing currents are within the following broad bands (although each manufacturer has narrower specifications and tolerances):

	No fire (amp)	*Firing impulse (mJ/ohm)*
Group 1 (sensitive)	0.2–0.28	1.6–5.5
Group 2 (insensitive)	0.65–1.2	15–140
Group 3 (very insensitive)	4.0–4.2	1000–2000

Detonators from one manufacturer only and of one type only should be used together in a circuit. Bridgewires from different manufacturers may vary in resistance, and the difference may lead to misfires.

Inductively coupled detonators are not normally susceptible to stray currents provided they are fully insulated and shunted. When several detonators of this type are used in one circuit, a careful check should be made that the inductance of the circuit is within the capacity of the special blasting machine.

Exploding bridgewire detonators (EBWs) and exploding foil initiators (EFIs) (see Section 5.2.3) are not susceptible to RF or stray current hazard because of the high firing impulse required. An additional safety feature is that they do not contain any primary explosive. These detonators are suitable where high security and simultaneity are paramount. They should also be used if there is a risk of the charge receiving rougher-than-normal handling, eg if an atmospheric diving system is to be used. A special blasting machine is required and there are inductance restrictions between the firing module and the detonators.

A blasting machine (exploder) with sufficient power output for reliable detonation of the number of detonators in the round should always be used.

See also HSE Offshore Safety Division *Safety Notice 6/91*(4.3).

4.6 DEPLOYMENT

4.6.1 Deployment of charges

Before lifting and lowering any explosive charge to the work site, a check should be made that any associated firing lines are free from knots, loops, kinks etc, that all ropes will uncoil freely and that there is more than sufficient length available.

Before deployment, firing lines should be physically checked by the supervising explosives engineer for damage and resistance/continuity. He should also ensure that the firing ends are shunted prior to connecting up the detonator. The resistance of the firing line should be measured separately using a special blasting ohmmeter then, if the resistance and number of detonators is known, the circuit can be accurately checked for completeness by simple arithmetic addition. In some situations it may be necessary to test the circuit's insulation with a blasting galvanometer against the steel of the work platform to check that the firing circuit remains isolated.

If ordinary electric detonators are being used and the circuit has more than one detonator and underwater electrical connections, the entire length of lead wire should be used. The lead wire is a factor in the resistance of a detonator and to alter its length will change its firing characteristics and parameters. It may also give misleading results when testing the resistance of the circuit and could lead to misfire.

4.6.2 Diver involvement

The explosives contractor should be satisfied that divers (and ROV pilots) handling explosives under water have had adequate formal training or experience to understand and comply with any precautions they are required to take on the instructions of the supervising explosives engineer.

As a general operating principle, explosives should be handled under water in the same way as they are on land. All explosives and accessories should be handled with care. In addition:

- divers should be careful not to come into direct contact with explosives; they should wear protective clothing as necessary
- on no account should explosives be transported inside a diving bell
- divers should be very careful when arranging and connecting explosive charges that they do not disturb charges already laid and that they do not disturb detonating cord runs and firing lines
- divers should be fully aware that all charges and lines should be made secure
- great care should be exercised especially when checking and leaving the operations area that firing lines are not caught in any diving equipment
- a set of signals should be agreed which can be employed should normal communications fail.

No divers, whether or not they are involved in the explosives operation, should be in the water in the vicinity of the explosives operations at the time the explosives are fired. Recommended minimum stand-off distances are tabulated in Section 6.4.2.

4.7 FIRING

4.7.1 Precautions immediately before firing

It is very important that the following precautions are observed, and written procedures in the form of a check list are strongly recommended. It is suggested that the procedures are distributed at a pre-firing briefing.

After the charges and firing lines have been positioned and the supervising explosives engineer is sure that everything has been checked, all divers and non-essential equipment (whether or not involved in the explosives operation) should be brought out of the water.

A check should be made that all unused explosives and accessories are locked and secured in the explosives magazine.

The work site should once again be checked by those designated (see Chapter 2) to ensure that everyone is at a safe distance.

Any relevant warnings to shipping should be given. No explosives should be detonated under or near any floating vessel or floating work platform without the consent of its captain. He in turn should ensure that all safety precautions for the integrity of his vessel have been taken and that any neighbouring vessels have also been informed.

A check should be made that any mechanical protection systems to be used are in place and correctly deployed.

The vessel or work platform may now move to its stand-off position, paying out the firing line or detonating cord as appropriate. Offshore, this distance should be calculated for the amount of explosive being used (see Section 6.5.2). When close to shore it may be more appropriate to calculate the amount of explosive that can be detonated on the basis of maximum available stand-off distances.

When the vessel (work platform) and whoever is to fire the explosive are in their respective positions, the supervising explosives engineer should again check with look-outs, etc to ensure that nobody has violated the specified stand-off distances. At inshore operations, sentries may be needed to stop the public inadvertently entering the blasting area. Adequate sentries should be posted to cover all means of access. For nearshore operations, both land-based and water-borne sentries should be deployed to prevent incursion into the specified stand-off distances and warn the supervising explosives engineer should this occur.

A final circuit check should be made immediately prior to connection to the exploder.

Some electrical methods of detonation may require radio and radar silence while the detonators are being connected up. See Section 4.5.3. Procedures for this should be agreed beforehand and adhered to throughout the project. In many cases, a calculation (see Appendix 3) can show that radio silence is not necessary. For a high power (hundreds of watts) low frequency transmitter within a few hundred metres of the detonator circuit, calculation is likely to over-estimate the hazard and, in an isolated case, radio silence may well be the best precaution. If the circumstances are likely to recur frequently, the actual value of RF power induced in the detonator circuit should be measured, the real level of risk established and a better-informed decision made on the need for radio silence. If silence is still shown to be necessary but the transmitter cannot be switched off, special detonators immune to RF emissions (such as EBW or EFI devices – see Section 5.2.3) will have to be used.

Only essential personnel should be present when final connections are made. The stand-off distances should be constantly monitored to prevent intrusion.

The supervising explosives engineer should check that any installed monitoring equipment is turned on.

Count down may then commence and the charge can be fired. Whoever fires the charge should make a note in his log of the time, the weight of explosive fired and special delays or other relevant firing details (eg number of charges).

4.7.2 Inspections after firing

Wherever possible after every round has been fired, the arisings should be inspected for possible unexploded material. When a single charge only is fired, it will be fairly obvious whether it has fired or not.

If no misfire is suspected or when electric detonation has been used, underwater inspection can be carried out by divers or a remotely operated vehicle (ROV) as soon as visibility permits. The divers should be fully briefed for what to look for, eg undetonated detonating cord, depending on the initiation technique used. When non-electric initiation has misfired, a wait of 30 minutes is normal before inspection. This is good practice and it is similar to that used on land although the likelihood of a fire under water is obviously remote.

On completion of inspection and if the divers report that there is no evidence of unexploded material, the area may be declared clear by a pre-arranged signal from the supervising explosives engineer.

4.8 MISFIRES

4.8.1 Causes of misfires

A misfire occurs when an initiation system fails to fire or an explosive fails to detonate as it was designed to. Misfires may be partial or total. In general the hazard from a misfire is directly related to the quantity and sensitivity of the explosive composition used.

Every effort should be made before firing to ensure that a misfire does not occur. Care, preparation, attention to detail and constant checking of all equipment and circuits before firing should reduce this possibility.

Causes of misfires include:

- movement of charges due to tide and current
- interruption in electrical elements of the firing circuit
- 'cut off' of detonating cord
- failure of detonating cord to carry over at a junction
- faulty or damaged detonators
- faulty, wet or damaged detonating cord
- insufficient power in the exploder
- alternating current used on a direct current firing circuit
- loss of coupling in the initiation train
- incorrect delay pattern
- current leakage
- short circuits
- insufficient priming or boosting of the main charge
- disruption of charges.

4.8.2 Misfire procedures

All explosives contractors should have a written misfire procedure and all misfires should be logged.

When a misfire is suspected or confirmed, look-outs, sentries and other personnel (eg captain, OIM, safety officer, etc) should be informed, and a check on stand-off distances should continue to be maintained. A careful and unhurried assessment of the situation should be made, primarily to establish the cause and extent of the misfire.

If it is considered feasible (ie if there is still a detonating circuit) the charge should be refired. If the round is considered to be electrically inert, then consideration should be given to reconnecting a fresh set of detonators and refiring.

If refiring is not successful, subsequent action is dependent on the type of explosive used and its location:

- *Bulk blasting*
  Where bulk blasting or plaster shooting have been used the source and cause of misfire should be easy to identify. If any of the charge cases are still intact, the charges should be treated just as the original material and fired accordingly – possibly with additional boosters as they will have been immersed in water for longer than planned.
- *Drilled charge*
  Where a partial misfire has occurred in a drilled hole under water, plaster charges correctly initiated are probably the best solution provided vibration and water-borne shock wave limits permit the use of such heavy charges. They may sympathetically detonate some of the undetonated explosive but in any event should loosen the ground to expose it.
  Drilling in the same hole as a misfire should never be attempted. Drilling relief holes in the same area should only be done with extreme care and accuracy.
- *Shaped charges*
  Where containers have been used (such as with shaped charges) they may have been filled

with a liquid explosive (eg nitromethene or hydrazine) or a slurry. Most of these compositions will mix with water and damaged containers should wash out. The miscibility of the composition should be checked with the manufacturer.
Any complete and undamaged containers should be refired in the normal way.

- *Charges in oil wells*
  If a misfire is suspected during the course of hydrocarbons-related operations such as drill collar cutting, junk shots and wellhead abandonment (usually because there is 'no result') the charge should firstly be made electrically inert. As the type of explosive used down the well should have a high insensitivity and should be temperature resistant, it should be relatively safe to try to recover it. If not, the only course of action is usually to attempt a further firing with an additional charge, as close as possible to the first. If this also is unsuccessful, the consequence of subsequent drilling detonating the shot in the well would have to be assessed by the supervising explosives engineer and the drilling engineer. Both should be fully aware of the situation and circumstances.

All actions and results throughout a misfire procedure should be logged.

Reporting undetonated explosives

If there is any possibility that undetonated explosives may be washed ashore, the local police and the client should be informed. Nevertheless, this action does not relieve the explosives contractor of his responsibility to ensure a clear and safe work site after his operations. The contractor's management should also be informed – there may be insurance cover consequences.

4.9 DISPOSAL OF UNUSED EXPLOSIVES

At the end of a project, any surplus explosives and accessories should be disposed of and, before this stage is reached, the explosives contractor should have agreed suitable procedures with the client. Alternative procedures include:

- Ideally, unused explosives and accessories should be returned to a licensed magazine or store onshore. If the explosives and accessories were officially exported (for use outside territorial waters) they will have to be similarly imported before being returned to the land magazine. This will entail informing the appropriate authorities, checking explosive limits for particular ports, etc (see Chapter 3 for details).
- Where return to shore is not possible or practical, the materials should be exploded, together with damaged cases and cartridges. The burning of explosives should never be attempted offshore. If there is only a small surplus this can be detonated (following the procedures of Sections 4.5–4.7). Any surplus detonators should be exploded last and on their own – they may be needed in case of misfire.
- Explosives that are soluble or miscible with water may be flushed away, but densities should be checked. Alternative methods of disposal should be used if any possibility exists that explosives may be washed ashore or trawled up.
- Boxes, cartons and outer and inner wrappings which have been used to contain explosives should be treated as contaminated. They should not be re-used or mixed with ordinary rubbish; they should be carefully inspected for any remaining explosive, kept separate and, depending on their nature, be disposed of onshore or returned to the manufacturer. The manufacturer should be consulted if there is any doubt about what to do.

Whichever method is used, consideration should be given to its effects on the environment and wildlife.

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5. Types of explosives and initiation

5.1 EXPLOSIVES

There are many types of explosives and most have been used under water in some context. However, very few have suitable properties for extensive underwater use, although some have been developed specifically for this role.

The main properties of each class of explosive are described here, together with any special hazards of toxicity, extreme sensitivity, particular advantages or shortcomings and examples of their application. Properties are summarised in Table 5.1.

5.1.1 General properties of explosives

The physical form of an explosive likely to be used under water may be:

- solid cast from a melt
- powder/granular, either loosely or firmly compacted
- mobile or thickened liquid compound or mixture
- a semi-solid mixture of thickened liquid with powdered solid.

Many explosives will be supplied cast or pressed into a filled item and they will not be visible to the user. In many cases the inner packaging will be left in place when the explosive is detonated.

The usefulness of explosives resides in their ability to deliver considerable amounts of stored energy at extremely high rates and at a precisely determined time and place, without bulky external power supplies or complex control systems. Because of their nature, they possess particular properties which determine their applications.

Velocity of detonation

The stored energy of a high explosive is delivered up very quickly during detonation. The detonation process is orders of magnitude faster than any burning reaction. Whereas combustion converts solid or liquid 'condensed' ingredients into gaseous reaction products by the transfer of heat from the reacting to the unreacted zone, a high explosive is converted into gas by the passage

Table 5.1 *Approximate* properties of high explosives used to make charges*

Explosive	Density (kg/m^3)	Velocity of detonation (m/s)	Detonation pressure		Explosive strength		Figure of insensitiveness (RDX = 80)	See Section
			(GPa)	(kbar)	Weight (% BG)	Bulk (% BG)		
Blasting gelatine (BG)	1550	7900	26	261	100	100	30–50	5.1.2
Submarine blasting gelatine (SBG)	1600	7500	24	243	95	98	30–50	5.1.2
Plaster gelatine (PG)	1550	6500	18	177	80	80	30–50	5.1.2
Gelatines	1400–1600	3000–5000	3–11	34–108	50–90	40–90	30–80	5.1.2
Trinitrotoluene (TNT)	1650	6900	21	212	60	64	150	5.1.3
Pentolite	1680	7500	26	255	77	83	100	5.1.3
Composition B	1660	7800	27	273	83	89	110	5.1.3
Cyclotol	1740	8250	32	320	89	100	90	5.1.3
Plastic explosives	1450–1600	7000–8000	19–28	192–277	74	73	100–140	5.1.4
Nitromethane/amine (NM/amine)	1120	6500	13	128	81	59	>100	5.1.5
Hydrazine nitrate/hydrazine (HN/Hz)	1300	8500	25	254	85	71	—	5.1.5
Urea perchlorate/nitromethane (UPC/NM)	1500	7000	20	199	81	78	>100	5.1.5
Methylamine nitrate slurry (MAN slurry)	1300	3500	4	43	78	65	>150	5.1.6
Aluminium sensitised slurry (Al-slurry)	1300	3500	4	43	62	52	>150	5.1.6
TNT slurry	1600	5500	13	131	68	70	>150	5.1.6
Smokeless powder slurry (SP slurry)	1550	5000	10	105	70	70	>150	5.1.6
Emulsions	1150	5000	8	78	61	45	>150	5.1.7
Emulsion/ANFO	1200	4000	5	52	68	53	>150	5.1.7
Ammonium nitrate/fuel oil (ANFO)	850	3500	3	28	75	41	>150	5.1.7

* *Actual values depend on formulation, particle size, configuration, initiation etc; approximate figures and ranges shown for guidance only.*

of a supersonic shock wave which induces reaction in the next slice of material. The speed of this shock wave is referred to as the velocity of detonation. Its significance is that it affects the violence of the effects of an explosion, by determining the time over which the energy in the explosive charge is released.

Velocity of detonation is measured in m/s or ft/s and practical values are in the range 2000–9000 m/s (about 6500–30,000 ft/s).

Detonation pressure

Detonation pressure is an important property which has replaced the older terms 'brisance' and 'shattering power', which had no absolute definitions and could only be expressed in arbitrary units. Strictly, it is the detonation pressure which determines the violence of the action of an explosive on adjacent and surrounding matter. It is strongly influenced by detonation velocity because it is obtained by multiplying the square of the detonation velocity by the density of the explosive and by a scaling factor.

Detonation pressure is seldom specified by manufacturers but, if required, may be obtained from the formula:

$$P = 2.7dD^2 \times 10^{-10} \quad \text{(in GPa)}$$

where d is the density in kg/m^3

and D is the velocity of detonation in m/s.

It is expressed in GPa or kbar (where 1 GPa = 10 kbar).

Explosive strength

Explosive strength is a measure of the work a given amount of explosive can do under conditions of normal use. Many methods are used for its measurement or calculation and there is general agreement between them. The usual value is a relative one, indicating the amount of work the explosive can do as a percentage of that obtainable from an equal amount of a standard explosive. It is important to specify whether equal volumes (for 'bulk strength') or weights (for 'weight strength') are being compared and which explosive is the standard:

- a *weight strength* of 70% BG means that 1 kg of the explosive can deliver the same amount of energy as 0.7 kg of blasting gelatine, ie 70% of the energy which could be supplied by 1 kg of blasting gelatine
- *bulk strengths* relate the energy available from equal volumes of the explosive and the standard, and it is evident that the bulk and weight strengths are related by the ratio of the densities of the explosive and the standard.

Blasting gelatine is the strongest commercial explosive and it has been chosen as a standard for that reason. Other standards are in use – picric acid (PA) because it can easily be prepared in a standard condition anywhere in the world and ANFO, a mixture of ammonium nitrate and fuel oil which is very widely used in quarries and opencast coal sites.

Stability

Although explosives can be made to deliver large quantities of stored energy very quickly, they are not necessarily unstable, and most of them may be stored safely for long periods under proper conditions. It is essential that the manufacturer's storage recommendations are followed. Extremes of temperature should be avoided, as should contact with potentially incompatible materials.

Sensitiveness

Explosives are tested during both development and manufacture to measure their sensitiveness to accidental external stimuli, eg mechanical impact, friction or electrostatic discharge. Mechanical sensitiveness may be measured with reference to friction or impact and is often given as the FOI, the 'figure of insensitiveness'. FOI compares the height from which a weight must be dropped in a standard apparatus to cause ignitions in half the samples of an explosive with the corresponding height for a standard explosive such as RDX, which is given the value 80. A number higher than 80 indicates a sensitiveness lower than RDX. The results of other tests are considered along with the FOI in classifying explosives as 'sensitive', 'very sensitive', or 'comparatively insensitive'.

Sensitivity

An initiation system is required to release the explosive energy on command (see Section 5.2). This is a relatively small charge, usually a 'detonator' or 'blasting cap', which converts a small flame or flash from a fuse or electric matchhead into a detonation wave. The main explosive charge is then itself caused to detonate, either directly by the detonator or by the larger impulse of an intermediate 'primer' or 'booster'. A main charge which requires such an additional charge has a lower sensitivity than one which is cap-sensitive, ie one that can be detonated by a detonator or blasting cap directly (this is usually taken to mean sensitivity to a No 6 detonator, though a No 8 may be implied).

Density

The density of an explosive is important because of its effect on detonation pressure and bulk strength. It is defined in kg/m^3 but is often expressed in g/cm^3 or simply as specific gravity.

5.1.2 Nitroglycerine-based explosives

Nitroglycerine (NG) was the first high explosive to be used, and because of its exceptional versatility it is still to be found in a wide range of explosives. It may be present as the principal ingredient or a minor one; the physical and explosive properties of the mixtures show correspondingly wide variations.

Blasting gelatine

This mixture of about 92 parts of NG with 8 parts nitrocellulose (NC) has a tough rubbery consistency and is very violent in its action. The very high velocity of detonation can only be reliably achieved when specially primed. It is unaffected by water.

Applications include metal cutting and direct attack on hard rock but in practice it is rarely used.

Submarine blasting gelatine

A small quantity of additional material can be incorporated into blasting gelatine to improve the initiation and propagation characteristics at depth, without significant loss of explosive strength.

Applications are as for blasting gelatine.

Plaster gelatines

Having lower nitroglycerine content than blasting gelatine, plaster gelatines are less expensive and more widely used. They may be off-white or black in appearance, depending on which additives have been used to assist propagation at the high velocity. Strength and velocity are both lower than blasting gelatine although the water resistance is still excellent.

Applications include metal cutting, charges for contact blasting or in holes drilled in hard formations.

Gelatines

To the basic nitroglycerine/nitrocellulose 'gel' the addition of increasing amounts of energy-producing mixtures of sodium and/or ammonium nitrate, woodmeal and other ingredients gives rise to a number of series in which the explosive strength is diminished while the density hardly falls and may even rise. Water resistance is also gradually reduced, these compositions being intended for more economical blasting on land.

As well as gelatines, other names are used such as gelignites and gelatine dynamites with prefixes such as 'straight', 'ammonia' or 'ammon-' to indicate the nature of the added ingredients. Sometimes a number is added to indicate the strength.

The higher grades are quite suitable for underwater use provided they are not to be placed at great depths or left in running water for a long period. Applications are in bulk contact charges, drilled holes and general underwater blasting.

Precautions to be taken with all nitroglycerine explosives

No NG composition should be used if it shows signs of liquid nitroglycerine separating on the surface. This should not be confused with the harmless solution of nitrates which can often be seen on the wrapper of a composition which contains a salt. Nitroglycerine has an oily appearance and remains as separate drops in water, while the nitrate solution dissolves immediately.

Liquid nitroglycerine is very dangerous. It is rapidly absorbed by breathing the vapour and through the skin and causes very unpleasant headaches. The danger is indirect as well as direct, the affected user possibly becoming distracted and failing to take safety measures.

NG compositions should only be handled in their wrappers, or wearing gloves.

5.1.3 Solid explosives based on TNT

Solid explosives based on trinitrotoluene (TNT) have high density, velocity of detonation and detonation pressure. Pressed charges can have high sensitivity; they and some cast ones may be encountered as boosters, for which they are particularly suitable. They are completely unaffected by water.

These explosives are generally too expensive for bulk use and they are mainly used as fillings in manufactured (eg shaped) charges.

Pentolites

Pentolites are mixtures of pentaerythritol tetranitrate (PETN) with TNT. The low melting point of TNT allows suspensions of the more powerful, but rather sensitive, PETN to be cast into charges which may then be handled with ordinary care. Powdered pentolite is also used as a pressed filling.

Composition B and cyclotols

Composition B and cyclotols are analogous mixtures of cyclotrimethylene trinitramine (RDX) with TNT. Small additions of wax are also sometimes made. On the whole, mixtures containing RDX are more powerful and less sensitive than corresponding ones containing PETN.

5.1.4 Plastic explosives

Plastic explosives are putty-like mixtures of a powerful high explosive in powder form with a liquid or grease which acts as both plasticiser and desensitiser. Common ones are PE4 and C4, similar mixtures both containing about 90% of RDX. Other explosives may also be used as the basis to form a group commonly referred to as plastic or polymer bonded explosives (PBE or PBX). Proper priming is essential, and detonators of adequate strength or small booster charges are required. Compositions in sheet form are also available and the more sensitive of these can be used for priming charges.

Plastic explosives are unaffected by water unless it is running so quickly that it breaks them up.

These compositions were originally developed for military demolition and now find much use in improvised charges for metal cutting. A wide range of plastic or polymer-bonded explosives is now available for military applications. They are expensive but have high performance and may find application for specialist tasks under water.

5.1.5 Liquid explosives

Nitromethane mixtures

Nitromethane explosives have only moderate detonation pressure and velocity because the densities are quite low, but they are very convenient to use, with adequate though not excessive sensitivity. Nitromethane is not normally cap sensitive but it can be sensitised by small quantities of amines. There are some sophisticated systems which maintain cap sensitivity only for a specified period after mixing.

These mixtures have been widely used as fillings for shaped charges in large metal or plastic containers for underwater trenching and rock breaking as a rapid alternative to drilling or where drilling is not possible.

Nitromethane is not corrosive, but the vapour should not be inhaled.

Hydrazine mixtures

Mixtures containing hydrazine and hydrazine nitrate in concentrated solution in water can be quite sensitive, and they have extremely high velocities. They may be clear or cloudy and may contain solids in suspension, especially when thickened.

They have been used for shaped-charge filling for immediate use but they are not intended to be stored in the mixed state.

Hydrazine is corrosive and toxic, and the strongly smelling vapours should not be inhaled. An advantage of these mixtures is that they can be quickly and completely dispersed by adding water.

Urea perchlorate explosives

Urea perchlorate explosives are not common but they may be found as dense solutions in water with one or more soluble fuels. Sensitivity depends on water content.

The liquids are quite dense and have been proposed for use under water as a dense liquid explosive layer in a borehole or trench, protected from the dissolving action of water by a liquid of intermediate density which does not mix with either water or the explosive.

Perchlorates are toxic and can enhance corrosion in the presence of water.

5.1.6 Slurry explosives or water gels

Slurry explosives or water gels may have one or more of a large range of sensitisers, but the most common ones are based on either methylamine nitrate or aluminium powder.

Methylamine nitrate slurries

Methylamine nitrate slurries have medium density and velocity of detonation and may be cap or cord sensitive. They have a texture like stiff porridge and have moderate water resistance. Though methylamine nitrate is itself explosive, these slurries are not regarded as 'explosive sensitised', since any material left undetonated after a blast will eventually absorb sufficient water from the air in any but the most arid of atmospheres to render it inert. In water, material not protected by its normal plastics package will disintegrate and disperse after a period of days or weeks, according to the conditions.

Methylamine nitrate sensitised slurries with high aluminium content are the strongest slurries available. Normal grades are suitable for underwater use down to moderate depths as advised by the manufacturer but require larger primers as the depth increases. Special types are made for greater depths.

Aluminium sensitised slurries

Aluminium sensitised slurries have similar water resistance to methylamine nitrate slurries but are not generally as strong. The texture tends to be more like clay than porridge and in appearance they vary from silvery to black. Cap-sensitive and cord-sensitive grades are available.

The aluminium used for this purpose is very fine flake or 'paint grade', not the coarser atomised material used for increasing the strength in other types of slurry. It is able to sensitise the reaction between a soluble fuel and a saturated nitrate solution, in which there are no 'self-explosive' ingredients. However, other ingredients such as sulphur (often used together with the aluminium) may form ignitable mixtures with the aluminium should the hygroscopic nitrates and the thickening agent be leached away under gentle washing. Any such residue should not be allowed to dry out and should be treated with care.

TNT slurries

TNT slurries – containing TNT, nitrates, thickener and water – are yellow to brown in colour. If they also contain aluminium, they have a grey appearance. Their bulk explosive strength can be high because of their high density, although their weight strength is only moderate. Sensitivity is not high but it is not reduced by hydrostatic pressure so the compositions are suitable for use in boreholes in hard rock under water where some time may elapse before the holes are fired. Adequate boosters are needed.

These compositions are likely to be found only at times or in areas where there is cheap surplus TNT.

Smokeless powder slurries

Smokeless powder slurries are similar in most respects to TNT slurries but they may be more powerful. Their appearance may be from off-white to brown.

Precautions to be taken with slurries

Slurries do not present the same immediate danger as other high explosives with respect to ignition, although some types with very low water content may be made to burn. The residue from any slurry can be dangerous if completely dried and, in a fire involving large quantities of slurry, some dried material may be able to burn vigorously enough to burn to detonation and initiate unaffected slurry.

Slurries sensitised by insoluble high explosives such as TNT and smokeless powder (a high explosive in this context as it can be made to detonate) can be particularly dangerous in conditions which wash away the soluble ingredients and leave only the high explosive. This residue can remain a potentially dangerous explosive indefinitely.

In practice, there is no case for relaxing any of the normal precautions for handling and storing explosives when using slurries.

5.1.7 Emulsion explosives

Emulsion explosives are similar to slurries or water gels in several respects – many of the ingredients are the same – but the structure is quite different. Because of this they can be more sensitive to detonation than most slurries and have relatively high velocities of detonation (although this cannot compensate for generally lower energy contents).

Some are particularly suitable for underwater work to medium depths, being less prone to pressure desensitisation than slurries (except those based on TNT or smokeless powder and those specially formulated). Water resistance is good, and their high velocities allow them to compete with the more effective but much more expensive plastic explosives when there are no restrictions on the quantity of explosive that may be used.

5.1.8 Emulsion/ANFO mixes

ANFO is the 94/6 mixture of porous 'prills' of ammonium nitrate and fuel oil which it is permitted to mix at the site where it is to be used, subject to the proper licence, as an exemption to the provisions of the *Explosives Acts 1875* and *1923* (see Section 2.3), which otherwise confine all explosives manufacture to a licensed explosives factory. The weight strength of the mix is reasonably high but the low density leads to very low bulk strength. In spite of this and the lack of any water resistance other than that provided by the package (if any), it is very widely used in quarries and opencast sites because of its simplicity and very low cost.

The combination of emulsion explosive and ANFO waterproofs the latter and makes use of its very cheap energy. The appearance of these mixtures varies with the relative proportions of the ingredients – from a grey porridge to an off-white, grey or brown putty. Proper priming is essential.

These emulsion/ANFO mixtures may find increasing use under water when large amounts of cheap bulk explosive are required with reasonable water resistance for a few hours. Any material not detonated will be dispersed harmlessly in the water.

5.2 INITIATION

5.2.1 Principles of initiation

To obtain the energy stored by an explosive charge and use it to work the target material, sufficient energy must first be applied to a volume of the explosive to cause reactive decomposition which will build up to a detonation. Provided that a large enough amount of the explosive reacts initially, the whole charge will then detonate as intended. Explosives differ considerably with respect to the ease with which they may be made to react (sensitivity) to form the products of chemical reaction and release the stored energy, and in each case a large enough impulse must be delivered to the charge to ensure proper functioning. For safety reasons, the sensitiveness of the main charge to impact, friction and other stimuli should be low. In practice, this often means that its sensitivity to the intended detonating impulse is also low.

Detonation usually originates in a detonator. This is a small device for converting the flash from the end of a safety fuse or from an electrically fired 'matchhead' into a detonation wave, and to do this it must contain a very sensitive primary explosive composition. For safety reasons, the quantity of this composition must be small and the impulse it can deliver is necessarily limited. The detonator therefore also contains a slightly larger charge of a more powerful explosive which, though less sensitive than the primary composition, is still sensitive enough to be detonated by it. This 'base charge' alone acts as a primer of sufficient size to initiate sensitive explosives such as those based on nitroglycerine, but ANFO and many slurries require an additional primer or booster.

A detonation wave passing through an explosive becomes a shock wave in whatever medium lies outside the explosive. The intensity of a shock wave falls off very quickly with distance so it is important to avoid gaps between any explosive component and another which it is required to detonate. All the components of an explosive charge must be held firmly in contact.

5.2.2 Initiation using primary explosives

Primary explosives are very sensitive and 'burn to detonation' immediately after ignition. The small amounts required in use are carefully packaged by manufacturers so that they can be handled safely with ordinary care. In the explosives context, 'ordinary care' means avoiding mechanical shock, high temperatures and electrical discharges and fields.

Plain detonators

A plain detonator is an aluminium tube open at one end with a small charge of a primary explosive (often a mixture containing lead styphnate and lead azide with a lubricant) pressed on top of a slightly larger base charge of an explosive such as tetryl or RDX.

It is intended to be ignited by the flash from the end of a length of safety fuse (a gunpowder core wound with textiles and waterproofed with pitch) which in turn has been ignited by a match or other means. The detonator is lightly crimped onto the safety fuse to retain it, but the joint is hardly waterproof, and the system is not suitable for general underwater use.

Detonators are manufactured with a range of strengths, the strength denoting the ability of the detonator to initiate high explosives. Historically, detonators with Number 6 strength were filled with 1 g of a mixture of mercury fulminate and potassium chlorate and Number 8 strength detonators contained 2 g of the mixture. Detonators with a so-called 'composite' filling of fulminate/chlorate and TNT or tetryl were introduced later. Although their charge weight is somewhat less (eg 0.4 g fulminate/chlorate and 0.4 g tetryl for a Number 6 strength), the initiating power is the same as those of the same number strength in the original series. Modern detonators have even smaller base charges of more powerful explosives but they retain the same initiating strength. Detonators with the same strength numbers but manufactured in different countries are supposed to be equivalent.

Hard-wired electric detonators

An electric detonator contains the same elements as a plain detonator but with the addition of a 'fusehead' or 'matchhead' – a small powder charge which ignites with a bright flash when the short length of resistance wire (sometimes called the 'bridge wire') is heated by an electric current passed down two wires which lead through a plastic sealing bung.

There is a short delay after the passage of the current before the detonation wave emerges from the bottom of the detonator. The delay is shorter when a larger current is passed, but there is always a minimum delay, which is too long for accurate enough timing for some jobs. In practice, the term 'instantaneous' is used to distinguish detonators which have no additional delay incorporated into them from the various series of 'delay' detonators. Series are made with additional delays in increments of 0.025 s (25 ms) in the 'millisecond' or 'short delay' range and 0.5 s in the 'half-second' range.

Special types of electric detonators which need very much higher firing current are used when there is a risk of stray or induced currents.

The colour of the plastic insulation of the wires is used to code the type of detonator and the delay series. The two wires may have the same or different colour but the codes unfortunately are not universally standardised.

Electric detonator strengths are the same as those of plain detonators with the same number strength. It is important to avoid confusion between the number of the delay increment and the strength number.

Electric detonators are satisfactory for use under water. Most are suitable for use down to approximately 25–30 m. They should not be left at this depth longer than is absolutely necessary as they can leak. Detonators are available for greater depths from the manufacturers.

Inductively coupled firing circuits

A novel electric system of initiation uses a single wire loop to carry an alternating current in the frequency range 10–20 kHz at the moment of firing. The wire is passed through one or more, usually several, ferrite torroidal transformers each encased in plastic with a hole in the centre. Each has its own secondary winding connected by twin wire to its detonator, which may be instantaneous or delay.

This system has improved safety because direct currents cannot pass to the detonators; they are electrically isolated from the firing circuit. The ferrite transformers are very broad band however and can couple efficiently at frequencies up to a few megaHertz. They should not therefore be relied upon for protection against RF emissions from low frequency high power transmitters operating at 2 MHz or lower – for example, marine band 400–600 kHz.

A system using a large area inductive loop to convey both the electric power and the firing signal to the detonators in a round of several remote charges has been used in Japan. The use of this very sophisticated method is likely to be confined to the most severe situations where 'hard-wiring' is impossible.

Non-electric initiation

Non-electric initiation systems can be based on a 'fuse' of a very thin coating of a mixture of HMX and aluminium on the inner surface of a small diameter plastic tube. They have been called 'shock-wave conductors' because a shock wave, not a detonation wave, causes the functioning of the detonators with which lengths of this type of fuse are terminated. They are particularly useful when it is not possible to rule out entirely the chance of stray or induced currents in an electric initiation system. They are also available in non primary explosive form (NPED).

Other types of system, using plastic tubes filled with an explosive gas mixture after emplacement, may also be attractive from the safety viewpoint but are far less convenient and reliable.

5.2.3 Initiation using non-primary explosives

For special purposes requiring very precise timing, initiation is sometimes achieved by the use of 'bursting wire' or 'exploding wire' detonators. When a capacitor charged to a high voltage (which may be several thousand volts) is discharged through a short resistance wire in a low inductance circuit, enough energy can be deposited in the wire to cause it to explode. The exploding wire may be able to initiate detonation directly in an explosive such as fine PETN, which is not a primary explosive. Sometimes the inductance of long wires necessitates the use of remote-firing units where the firing current travels a shorter distance than the firing signal, but this greater complexity can only be justified in special circumstances.

Another version of a high voltage detonator which does not contain a primary explosive is the 'slapper' or 'flyer plate' detonator, also known as EFI (exploding foil initiator). It has similar input firing characteristics to exploding wire detonators but is more robust mechanically and less affected by the ingress of a small amount of water. In operation, a capacitor charged to a high voltage is discharged through a metal foil bridge element which is bonded to a plastic sheet. The metal foil vaporises and projects the plastic sheet at a velocity of several km/s. The flying plastic sheet impacts a receptor explosive pellet (generally PETN or HNS), causing it to detonate.

From the point of view of accidental detonation through mechanical damage, bursting wire or flyer plate detonators are much safer than detonators that use primary explosives, although there can be problems with insulation because of the high voltages involved. High voltage firing circuits store lethal amounts of electrical energy, and this aspect of safety should not be overlooked.

5.2.4 Detonating cords

A detonating cord consists of a core of high explosive, almost always PETN, in a wound textile casing with an extruded waterproof plastic skin. It may be regarded as a flexible, linear detonator and can be used to transmit detonation over a considerable distance. Special cords used in hostile environments have casings of other plastics or metal and fillings which can withstand the effects of temperature, pressure and oil or well fluids.

Several explosive loadings are available and are expressed both in g/m and in grains per foot. The most common has a nominal explosive content of 10.4 g/m (50 gr/ft) but heavier loadings such as 40 g/m (200 gr/ft) cord is often recommended for underwater use, especially when priming a main charge is required. The normal velocity of detonation is 6500 m/s.

Any number of branches may be made by wiring, or preferably taping, the branch and trunk lines together over a sufficient length. Care should be taken that the cords are connected so that the detonation will travel in the intended direction, because the detonation wave will not normally propagate backwards from a junction. Cords may also be joined by knotting, as advised by the manufacturer, but continuous lengths should be used if possible.

The plastic layer prevents water penetrating the walls of a detonating cord but it may get in at the ends. The sensitivity of wet cord is reduced, but propagation is not impeded, so adequate priming of wet cord is essential. Ends should be sealed if possible. Dry cord can be initiated by a Number 6 detonator in air. Manufacturer's instructions should be followed for initiation under water. Detonating cord may be used to great depths but additional boosting (by the use of a primer) as advised by the manufacturer may be required at joints and special attention is needed to sealing the ends to prevent the hydrostatic head forcing water into the core of the cord. Detonating cord of a high quality and of a high explosive loading should be used at greater depth.

5.2.5 Arrangements for multiple firing

Many underwater blasts are fired as a 'round' of several charges. Often it is important that they should be detonated simultaneously or in a particular sequence at precisely controlled intervals. In either case the detonator must function with the least possible uncertainty in its timing.

Detonating cord

Detonating cord may be used to fire multiple charges of any kind, but care should be taken to prevent both unwanted cross-initiation (with consequent premature firing of some charges) and 'cut offs' in which the cord is severed before the arrival of the detonation wave so that a group of charges is not detonated at all. A group of shaped charges arranged to cut a metal section must be initiated within a few millionths of a second of each other, or spurious initiation at an incorrect point in the explosive filling of one charge induced by the earlier action of another may prevent one or more charges from cutting the target. Use of correct lengths of detonating cord allows this to be done properly. Even 'instantaneous' electric detonators have too large a time dispersion, and their use will result in one or more of the charges failing to cut.

Multiple detonators

A series of delay electric detonators is often used to fire several shots together in an array of boreholes – to reduce environmental effects or to enhance the action of the blast in a particular direction (eg to clear the debris from a trench). Series, parallel and various combined circuits can be used to allow the required number of instantaneous or delay detonators to be fired from a single exploder. The advantage of this system is that all the detonators are activated before the firing circuit can be interrupted.

Switching circuits

Very precise timing, at least to the degree required in shotholes, is possible using a sequential multi-shot exploder, sometimes called a 'blasting machine', although the task of making the right connections may be considerable with a large number of charges. Care should be taken that early charges do not cut the circuits of later ones.

Non-electric systems

Multiple shots may be fired with non-electric systems, special connectors being available to introduce a standard delay increment at each junction.

5.2.6 Remote initiation

Special devices are manufactured to enable underwater charges to be detonated remotely on receipt of an acoustic or electromagnetic (radio) signal transmitted through the water. The signal may be coded, to prevent detonation by spurious signals, and some of the devices may be remotely armed and disarmed. The device cannot be fired before arming or after disarming in the case of an aborted firing.

When a charge has to be fired at some time in the future or if it has been placed at a location that cannot be reached by acoustic or radio signals, an initiator fitted with a timer may be used. The timers may use a crystal-controlled clock, and they can be set to function at a precise time after many hours or even months.

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6. Pressure waves from explosions

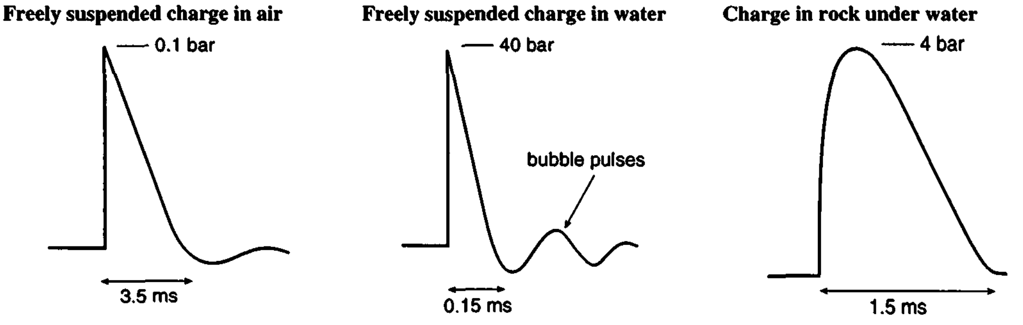
6.1 INTRODUCTION

6.1.1 Categories of blast exposure

The blast wave arising from the detonation of explosives under water differs substantially from blast in air and the likelihood of injury and its nature may differ for each. In the context of these *Guidelines* there are three main categories of blast waves:

- blast from explosives in air
- blast from explosives freely suspended in water
- blast from explosives embedded in boreholes in underwater rock.

Figure 6.1 illustrates typical waves for the three cases at a range of 10 m from a charge of 1 kg of TNT.



Typical values for 1 kg charge at 10 m:
Peak pressure: 0.1 bar
Peak air displacement velocity:450 m/s
Duration: 3.5 ms
Displacement caused by wave: 1.5 m
'Thickness' of wave: < 5 m

Typical values for 1 kg charge at 10 m:
Peak pressure: 40 bar
Peak water displacement vel: 2.5 m/s
Duration: 0.15 ms
Displacement caused by wave: 0.5 mm
'Thickness' of wave: < 1 m

Typical values for 1 kg charge at 10 m:
Peak pressure: 4 bar
Peak water displacement vel: 0.25 m/s
Duration: 1.5 ms
Displacement caused by wave: 0.5 mm
'Thickness' of wave: 2.5 m

Figure 6.1 *Typical shock wave profiles for explosions in air and under water*

6.1.2 Explosions in air

An explosion in air results in:

- a steep-fronted *shock wave*, rising in a few microseconds (μs) and decaying over a few milliseconds (ms), which becomes manifest as a pressure pulse which radiates from the explosive source at approximately the speed of sound in air
- a *negative pressure component* immediately following the shock wave
- high transient *blast winds* because air is light and compressible. These accompany the pressure variations and may be positive or negative in direction with respect to the explosive source. Velocities are typically 200 m/s but may exceed 400 m/s, depending upon the maximum overpressure of the shock wave and the type of explosive. The air displaces a distance of about 2 m.
- *other effects* such as fire and ground shock which make major contributions to the blast damage.

Because the rise time of the shock wave is of the order of a few microseconds, tissue shearing may result as the wave and associated displacement impinge on and pass into a body close to the explosion. During the rest of the passage of the wave, air-containing structures of the body are rapidly compressed inwards ('lung squeeze'). The result is that injuries tend to be associated with both whole-body displacement and with differential displacement of body tissues. In addition to these primary effects of the blast, secondary injury may be caused by the impact of flying debris, and tertiary injury by the whole body being thrown by the blast.

6.1.3 Explosions in water – freely suspended charge

The phenomena of air blast and underwater blast are analogous, but the values of the several components are very different (and the pattern of blast injury varies accordingly – see Chapter 8). Water as a medium is much less yielding than air because of the difference in density (water is approximately 800 times more dense than air) and the difference in compressibility (water is approximately 10 000 times less compressible than air). Other factors being equal, corresponding values for pressure are therefore much higher in an underwater shock wave compared with an airborne shock wave and one consequence of this is that the lethal range for a given charge is three times greater in water than in air.

The mechanisms involved are complex and still not fully understood, but an explosion freely suspended under water results in:

- A *shock wave*, rising to its maximum in the order of a few microseconds and decaying in less than a millisecond, which propagates radially at approximately the speed of sound in water, 1500 m/s (4900 ft/s). The peak overpressures produced are considerably greater than those produced in air by a charge of the same weight (see Figure 6.1). Because of the short rise time and despite the high speed of sound in water, the sharp change in pressure of the wave occupies only a few millimetres in space, and the whole wave less than a metre. The displacement of the water is typically only a millimetre or so, and hence there is not the significant blast wind associated with blast in air.
- *Subsidiary pulses* when the shock wave is reflected from the seabed, some in-water structures or the surface. Reflections from structures and from the bottom reinforce the direct shock wave, increasing both its peak pressure and the pulse duration. The surface reflection, on the other hand, is a negative pressure (tension) wave, closely following the direct shock wave and accelerating its decay to zero. Multiple reflected waves from the surface and bottom further complicate the situation and, following large explosions in shallow water with a very reflective (hard) bottom, multiple successive subsidiary pulses may impinge upon a point at mid-water depth at long range and give rise to resonant effects causing disproportionately severe injury or damage to a structure. A point on the surface at the same range might well be unaffected.
- *Water displacement* analogous to the transient winds of an in-air explosion. Passage of the shock wave communicates an outward radial velocity to the water which at short range surges to and fro in much the same manner as the blast winds of the explosion in air, producing a 'water-ram' effect. The velocity of this water movement is very small by comparison, typically a few metres per second, although a mass of water travelling at that speed can inflict severe injury on a diver who is 'water-backed', ie not at the surface.
- *Bubble pulses*. As the hot gases expand, the surrounding water is thrust back until the explosion bubble reaches its maximum diameter – about 25 times that of the original explosive solid. Then, as a result of the excess pressure, the water surges back and the bubble begins to collapse; when it reaches a minimum a pressure wave is propagated known as the bubble pulse. The bubble then re-expands and collapses and the process is repeated as the bubble migrates towards the surface, where the water is hurled into the air as the characteristic 'plume'. The peak pressure of the successive bubble pulses is usually much less than that of the corresponding shock wave but the time constant (pulse duration) is greater so that the energy and the impulse of a bubble pulse are approximately the same as those of the shock wave. Passage of the bubble wave, like that of the shock wave, is followed by an after-flow of water movement.

Because the peak pressure level from underwater blasts is extremely high. the severity of injuries from primary effects may be greater than those likely from similar charges in air. Pulmonary injuries may be caused both by spalling, where lung tissue is flung off at the interface with the air in the lungs, and by the rapid inward compression of the lungs where the pressure wave acts over a greater time period. Shearing of body tissues may occur during the sharp onset of pressure rise. Bubble pulses may coincide with the resonant frequency of a swimmer's lungs, with a consequent potential for increased pulmonary damage. Because of its density, the movement of the water following a blast freely suspended in water is much lower than in air, and tertiary injury caused by a body being thrown is thus unlikely. Secondary injuries caused by impact of debris are also unlikely due to the shielding effect of the water.

6.1.4 Explosions in rock under water

Pressure waves are substantially modified when underwater blasting involves the use of charges buried in boreholes to fragment rock prior to dredging(6.1). Peak pressure is reduced substantially, to 5 percent or so of the value for freely suspended charges, and impulse to about 30 percent. No bubble pulses occur. However, the duration of the shock wave is increased tenfold, typically to 1–2 ms (see Section 6.2.3). The rise time of the wave is greatly extended to the order of a millisecond.

The capacity of the shock wave to cause injury by shearing of body tissues is probably reduced because of the greater rise time but pulmonary injuries, which are related to the impulse of the wave, are still to be expected (although there is an absence of relevant case histories).

6.2 DEEP WATER SHOCK WAVES

This section introduces the fundamental properties of explosively generated shock waves and their physical laws and indicates the mechanisms by which energy from an underwater explosion far from boundary surfaces travels through water.

6.2.1 Pressure waves in water

Explosively generated pressure waves are an extreme example of sound in water, and sound is generated by any process that can cause a non-steady pressure field to occur. The pressure is fundamentally related to the rate of change of the displacement of the water by the source. When this is small, the pressure is low and the pressure wave that radiates through the water does so without any change in its basic waveform, other than being delayed by the propagation and reduced in overall amplitude by a factor proportional to $1/R$, where R is the range or distance from the source. This is illustrated in Figure 6.2.

Although shock waves generated by explosives do not propagate in an identical fashion to small acoustic waves (they change waveform during propagation), they may usually be approximated by this simple model over small changes of range. In addition, many of the gross features of propagation, such as attenuation by reflecting surfaces, are similar.

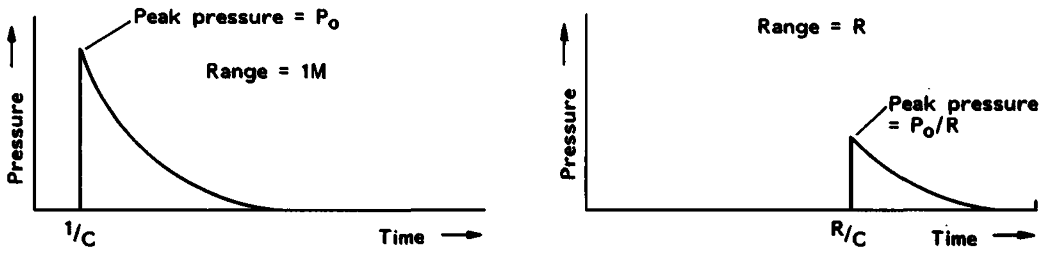


Figure 6.2 *The scaling and delay of a pressure waveform during propagation*

6.2.2 Shock waves from underwater explosions

The pressures in the water close to an underwater explosion are so large that the pressure waveform changes during propagation, forming a 'shock wave'. In the case of an underwater explosion of a freely suspended charge, the initial mass of explosive becomes a superheated bubble of gas at high pressure. The boundary of the bubble moves supersonically outwards, creating a wave disturbance in the water which is transmitted to other points at a velocity which is (except in the immediate vicinity of the charge) determined by the velocity of sound in the water – which is much higher than in air due to the relative incompressibility of water. Following the detonation, the pressure wave radiates spherically outwards at the speed of sound, about 1500 m/s (4900 ft/s). Near to the charge, the peak pressures superimposed in the fluid by the explosion are immense, but they are gradually reduced by increasing range as the energy carried in the wave is spread over an increasing area. The shock wave, as measured at a remote point, is characterised by an extremely rapid (for practical purposes instantaneous) rise in pressure to a peak value, followed by a more gradual decline back to the static pressure, typically over a few milliseconds. The decline in pressure is approximately an exponential decay, the timescale of which depends upon the distance from the charge.

At increasing range, the shock wave is sufficiently attenuated that propagation occurs more or less as a normal sound or pressure wave.

6.2.3 The role of peak pressure and impulse in damage criteria

It is not possible to make an accurate prediction of the form of the shock wave from an explosive charge by analytical means. Empirical laws have been determined by systematic experiments(6.2) and are used to estimate important parameters of the shock wave produced by a given charge. Two characteristics of the shock wave from an explosion are commonly used as a measure of its severity:

- the peak pressure, P_{max}, easily measured from a recording of the shock wave or estimated using the results of Table 6.1
- the impulse, defined as the integral of pressure over time, so that the impulse at a position is given by:

$$I = \int_0^\infty P(t)\,\mathrm{d}t \qquad (6.1)$$

  where $P(t)$ is the pressure of the shock wave recorded at that position at time t after the blast. An alternative way of stating this equation is that impulse is given by the effective, or average pressure of the wave multiplied by its duration.

The importance of impulse arises from the fact that, for many structures, a pressure wave acting over a given length of time will have the same effect as, for instance, a pressure wave of half the pressure but twice the duration. Both of these waves would have the same impulse.

Table 6.1 *Peak pressure, impulse and duration for TNT-based explosives*

Parameter	Symbol	Value	Unit
Pressure	P_{max}	$5 \times 10^7 W^{0.27} R^{-1.13}$	Pa
Impulse	I	$6 \times 10^3 W^{0.63} R^{-0.89}$	Pa.s

W is charge weight in kg
R is range in m
Source: Ref 6.2

Vibrations

Structures in water exposed to an underwater shock wave usually vibrate or resonate at a natural frequency following the wave:

- Where the frequency of vibration is low (ie the bulk of the shock wave arrives during one half-cycle of the notional frequency of the structure) the impulse of the wave determines the amplitude of vibration and hence the likelihood of damage. Structures with low natural frequencies include quays, jetties, dams and other heavy 'limp' structures, and damage criteria for them tend to be based on maximum permissible levels of impulse rather than on peak pressure levels.
- Light stiff structures tend to resonate at high frequencies so that the duration of the shock wave is relatively long in comparison with the response of the structure. The amplitude of vibration tends to depend only on the value of the initial pressure step of the shock wave (ie on its peak pressure). The human ear is a light stiff structure, hence criteria for hearing damage tend to be based on peak pressure rather than impulse.
- Where the duration of the shock wave is comparable with the period of response of the structure, the likelihood of damage is much more difficult to define and depends on specific features of the waveform.

These effects are independent of the source of the shock wave and they are equally applicable to shock waves in shallow water as well as deep water.

6.2.4 Limitations of deep water assumptions

Sections 6.2.1–3 above describe the effects of a freely suspended explosive charge in a sufficient volume of water that all boundary effects may be ignored. In the more general case of explosives operations in shallow water, boundary effects cannot be ignored and the ways in which the free water surface and seabed modify the shock wave are discussed below in Sections 6.3.1 and 6.3.2.

However, where the reflecting surfaces are considerably further away from the explosion than the point under consideration, the reflected wave is sufficiently attenuated by spreading to be of no significance. This is generally true when the charge-to-structure range is less than one-fifth of the charge-to-reflecting surface range (see Figure 6.3). Impulse and peak pressure levels can then still be calculated using Table 6.1.

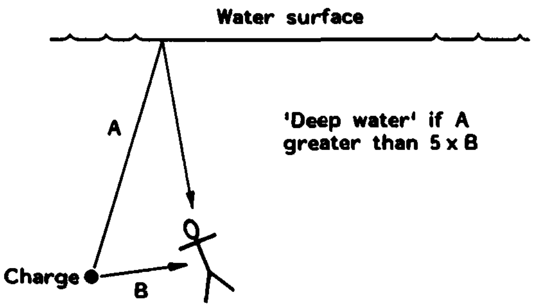


Figure 6.3 *Limits of 'deep water' assumptions*

6.3 SHALLOW WATER SHOCK WAVES

This section introduces the mechanisms by which the free water surface and seabed modify the impulse and peak pressure from an explosive charge.

6.3.1 The effect of the water surface

In theory, because the impulse and peak pressure arising from charges of high explosive suspended in deep water are well documented, it is a simple matter to calculate a maximum size of charge below which no injury or damage should occur. In one respect this represents the worst case since charges in blasting operations are buried in bedrock beneath the seabed and the impulse and peak pressure are consequently reduced. In fact, the maximum charge weights calculated by this method are unrealistically small because it ignores the effect of the free water surface in attenuating the impulse. A swimmer or structure near a water surface receives not only the shock wave radiating directly from the explosion but also the reflection of the shock wave from the free water surface. Because the acoustic pressure at the surface must be zero (due to physical considerations) this reflection is inverted, ie it is a wave of rarefaction or negative pressure rather than of compression. Its effect is thus to reduce the impulse, and hence the effect of the explosion. This effect is greatest nearest to the surface, so **a good rule for swimmers is 'the shallower, the safer'.**

In addition to being inverted, the surface-reflected pressure wave is also attenuated and delayed because of the greater path length it travels. The effect of the surface reflection is to reduce the average value of the pressure of the combined shock waves and hence to reduce the overall impulse. The effect of the water surface is simply to attenuate the total impulse by a value dependent upon simple geometric parameters. This attenuation factor is termed the 'impulse reduction coefficient', *K*. The value of this coefficient is illustrated in Figure 6.4 as a function of geometric ratios. More details of the method of calculation are in Reference 6.3.

If the range of the diver from the explosive charge is 'large' (ie if his horizontal range is at least twice as great as his depth and twice as great as the depth of the charge) the total impulse due to the direct shock wave and reflection, I_T, may be approximated by:

$$I_T = I_D\left(\frac{2\alpha dh}{R_H^2}\right) \qquad (6.2)$$

where d and h are the diver depth and charge depth respectively
R_H is the horizontal range
I_D is the equivalent direct (or 'deep water') impulse calculated from Table 6.1
α is the exponent of the term in R in the impulse equation, which for TNT-based explosives is about 0.89 (see Table 6.1).

An assumption is made in this approximation that the inverted pressure wave is reflected from the surface without distortion. In fact, it may be argued that water is incapable of sustaining a negative acoustic pressure of greater than about one atmosphere, because cavitation (ie local vaporisation of the water) will occur at lower pressure. This would limit the maximum negative pressure available and hence the attenuation of impulse. In the context of stand-off distances for divers, this is unlikely in practice since typical acoustic pressures at the stand-off distance do not approach this limit. However, for structures (where the allowable pressure is higher) this limiting effect may occur.

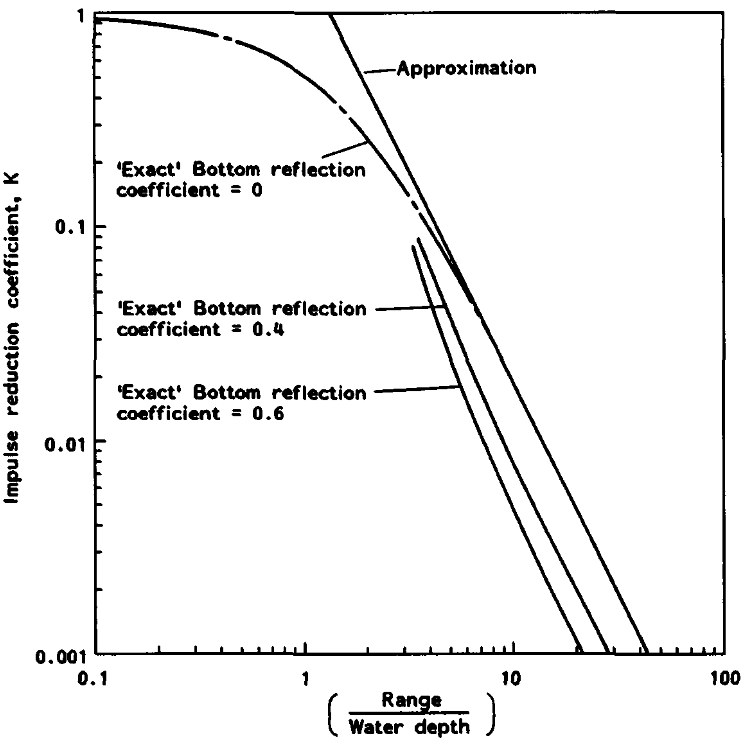


Figure 6.4 *Impulse reduction coefficient, K, as a function of geometric parameters*

The impulse is calculated for the worst case of both the charge and diver being at maximum depth, ie on the seabed. A lower impulse will result if the diver is nearer the surface, as indicated in Section 6.3.1.

An additional effect of the surface reflection is to extend the duration of the wave, since the reflection is delayed. This may be of importance in the context of structural vibration (see Section 6.2.3) because the total wave must arrive within one half-cycle of resonance of the affected structure if impulse is used as a criterion for damage. For large ranges, the time by which the pulse is extended is:

$$\Delta t = \frac{2dh}{Rc_0} \qquad (6.3)$$

where c_0 is the speed of sound in water, at least 1480 m/s.

For typical ranges associated with underwater explosives operations, the value of Δt is very small and hence Equation (6.2) may be applied without modification.

For freely suspended charges, it has been noted in Section 6.2.2 that the peak pressure of the shock wave is effectively reached instantaneously. As a consequence, the delayed surface reflection cannot act to reduce the peak pressure (see Figure 6.5). The maximum value of peak pressure from Table 6.1 is therefore appropriate for shallow as well as deep water for freely suspended charges.

6.3.2 The effect of the seabed

The calculations and approximations above have considered only explosions near the surface of deep water (ie where explosive energy radiating downwards is not returned). As illustrated in Figure 6.6, the pressure measured at a point remote from an explosive charge in shallow water has contributions from three main categories of wave:

- the direct shock wave
- the surface-reflected wave
- multiple-reflected waves occurring between the surface and the bottom.

The pressure wave due to both the direct wave and the surface-reflected wave can be calculated as described in Section 6.3.1. The effect of the multiple reflections may be calculated relatively easily (although tediously) using the method of images(6.3).

The shallow-water impulse reduction coefficient, K, has been illustrated in Figure 6.4 for a range of values of bottom reflection coefficient, B. This coefficient allows for the fact that not all of the acoustic energy striking the seabed is reflected back into the water. For the worst case, when $B = 0$, the impulse reduction coefficient is the same as that given by Equation 6.2 (the

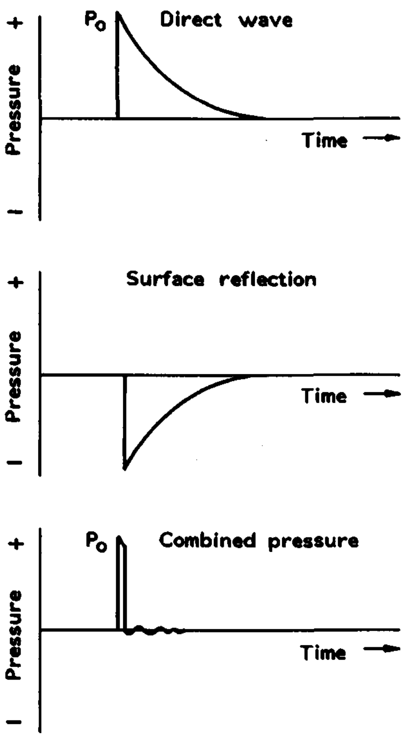


Figure 6.5 *The combination of the direct wave with the surface reflection to give a composite wave of equal peak pressure*

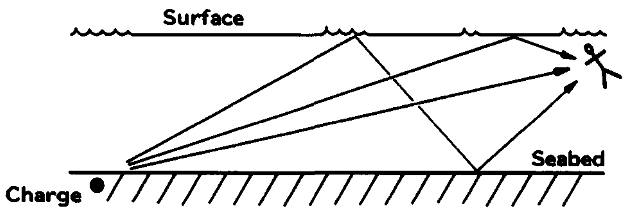


Figure 6.6 *Multiple pathway of pressure waves in shallow water*

circumstances are similar to deep water when all acoustic energy travelling downwards is lost). Because the acoustic nature of the seabed is rarely known, this value should be adopted when calculating impulse.

In calculations of the level of pressure and impulse, the explosion source is considered to be located at the surface of the seabed. When the explosive charge is buried below the seabed, any losses in peak pressure and impulse occur due to transmission of explosive energy from the explosive charge via the intervening rock to the seabed itself. They are thus common to all categories of wave and act to reduce the total pressure and impulse in proportion (see also Section 6.1.4). Another effect of burying explosives is to extend the duration of the direct shock wave in the water, with the peak pressure occurring some time after the onset of the wave. Interaction of the direct shock wave with the surface reflection will then substantially reduce the peak pressure at large ranges, in addition to the general reduction of the pressure arising in the water due to the intervening rock.

6.3.3 The headwave

In addition to the waves listed above, there is one other further wave that may result from an underwater explosion, the headwave. This wave propagates in the rock surrounding the charge and is eventually refracted upwards into the water. Since the velocity of sound in rock is higher than in water, it usually precedes the main water-borne waves. Its importance depends upon the nature of the seabed.

There is no evidence to indicate that the headwave is significant when determining appropriate stand-off distances.

6.4 EFFECTS OF SHOCK WAVES ON DIVERS AND SWIMMERS

6.4.1 Levels of shock exposure

The injuries associated with exposure to underwater explosions are reviewed in Section 8.2 'Blast injury'. In the context of this section here, it is worthwhile noting that the mechanisms of injury to the human body following exposure to underwater blast are only poorly understood and many observed features cannot be explained by the simple theory currently available to model shock wave propagation into the body.

It is probable that the appropriate choice of injury criteria for divers exposed to underwater shock waves depends upon the resonant frequency of the system involved (see Section 6.2.3). Experiments on anaesthetised rabbits(6.4) have shown that lung damage is related to a low frequency mechanism which, if scaled, indicates a resonant frequency of about 20–60 Hz for humans. High frequencies may be relatively unimportant under water and, if so, the injury criterion for this mechanism should be based on impulse rather than peak pressure. High frequency injury resulting from compressional wave propagation into the body is related to the peak pressure of the shock wave, and hence it is also necessary to adopt a maximum limit for peak pressure in order that injuries caused by this mechanism are avoided.

Various levels of both impulse and peak pressure have been quoted as limits of waterborne shock beyond which injury will occur. *Christian and Gaspin*(6.5) quote a maximum pressure of about 900 kPa and a maximum impulse of 40 Pa.s. *Delius et al*(6.6) have reported using peak pressure levels of 3600 kPa in the medical field (to destroy kidney stones) without damage, but in association with a lower impulse of about 7 Pa.s.

Conservative maximum limits of 170 kPa for pressure and 14 Pa.s for impulse are suggested as maximum single-exposure levels.

No information is available regarding the cumulative effect of repeated exposures in the diver. Until more information is available, this should be regarded as a potentially hazardous situation and should be avoided.

6.4.2 Stand-off distances for swimmers and divers

The data in Table 6.1 may be combined with this suggested maximum peak pressure of 170 kPa to yield a minimum stand-off distance in respect of peak pressure, R_1 (in m):

$$R_1 = 150\ W^{0.32} \tag{6.4}$$

where W is the charge weight (in kg).

Combining the impulse level of 14 Pa.s with Equation (6.4) gives the minimum stand-off distance in respect of impulse, R_2:

$$R_2 = 22.5\ W^{0.2}\ d^{0.33}\ h^{0.33} \tag{6.5}$$

where d is the diver's depth (in m) and h is the charge depth (in m).

The larger value, R_1 or R_2, should be the basis of the minimum stand-off distance required.

Table 6.2 lists calculations of these ranges for typical charge and depth values. The assumption has been made when calculating impulse that both the charge and diver are on the seabed. The values of R_1 and R_2 represent stand-off distances within which injury may occur and thus an additional safety factor should always be applied.

Table 6.2 *Stand-off distances for swimmers (in water not exceeding 50 m deep) calculated for maximum pressure of 170 kPa and maximum impulse of 14 Pa.s*

Charge weight (kg)	Pressure stand-off distance, R_1 (m)	Impulse stand-off distance, R_2 (m) Depth (m) 10	20	50	Recommended minimum stand-off distance* (m)
10	320	160	260	470	600
20	400	190	300	540	750
30	460	200	320	590	900
40	500	220	340	620	1050
50	540	230	360	650	1200

**Source: Ref 6.7 (where a safety factor has been applied)*

The factored values in Table 6.2 have been abstracted from *BS 5607:1988 Code of Practice for Safe Use of Explosives in the Construction Industry*$^{(6.7)}$. For explosives operations in waters deeper than 50 m (ie typical of much of the North Sea) reflections between surface and bottom may lead to a complex shock waveform and a blast impulse significantly higher than predicted by Equation (6.5). Safety factors of the size implied by Table 6.2 (ie 1.25 to 1.9) may then be inadequate, especially for charge weights greater than 50 kg.

'Funnel' effects

The stand-off distances of Table 6.2 apply to 'open water', far from solid structures. Where either the explosive charge or a diver is near a solid structure, the direct shock wave is augmented by a reflection from the structure. (Solid structures in this context are flat vertical walls of quays, jetties, dams and similar massive structures and the sides of large boats, but not 'open' structures such as lattices, well-spaced piles or pontoons.)

The peak pressure is unaffected by the reflection, and hence the stand-off distance R_1 may be calculated from Equation (6.4) without modification. But the stand-off distance with respect to impulse, R_2 of Equation (6.5), should be increased by 40% for every solid structure within two water depths of charge or diver. For example:

- a charge detonated near a quay wall in otherwise open water would require an amended impulse minimum stand-off distance of 1.4 times that indicated by Equation (6.5)
- a diver located in the corner of a harbour (ie near two solid walls) and exposed to a blast in another harbour corner (ie with the charge near another two solid walls) is exposed to potential injury from high impulse levels if his distance from the charge is approximately 4 times that indicated by Equation (6.5), in fact a multiplier of $1.4 \times 1.4 \times 1.4 \times 1.4$.

The increased effect of the explosive charge may be considered to be a consequence of the walls funnelling energy from the explosion towards the diver. Far more efficient funnels are provided by walls that form gradually converging channels, such as the penstocks of hydro-electric power stations or at the foci of sharply curved walls, and for this reason particular care should be taken when blasting within such funnels and divers should be evacuated from them even at large ranges. The impulse and peak pressure from the charge cannot readily be calculated, and estimates should be made from either scale experiments or test charges at full scale (see Section 7.1.3).

6.5 STRUCTURAL RISK

The effects of underwater pressure waves on nearby structures such as jetties, quays, pontoons and ships frequently limit the size of charge that may be used in underwater explosives operations. Propagation through the water occurs as described above, but seabed-borne waves may also affect structures that have foundations in or on the bedrock.

The formulae and ranges quoted below in Equations 6.6–6.8 have been developed on the basis of normal blasting operations using moderate charge weights. All unusual operations, particularly those using large charge weights, should be treated with extreme caution. It must also be emphasised that the stand-off ranges indicated are a guideline, and the factor of safety applied should be in keeping with the risk involved in the operation. Inevitably, situations will occur where a structure that was unsound prior to blasting is damaged by a small additional load imposed by blasting, even where this is much below the level that would be required to damage the same structure in good condition. Conversely, blasting is frequently conducted in close proximity to drilling pontoons at ranges much less than those indicated as a safe stand-off range without damage. In the extreme, even where no damage has been caused, the action of blasting may draw attention to existing damage which will then be blamed on the blasting operation. In all cases, the safety factor applied when calculating charge weights should take account of the integrity of the structures involved and the acceptability of damage, however slight.

6.5.1 Massive structures

During explosives operations near massive structures such as jetties, quays, seawalls, buildings, etc that have foundations on the underlying rock, there are essentially two independent effects of the blasting upon the structure:

- the effect of the waterborne pressure waves causing motion of the structure from the substantial forces superimposed on the underwater surfaces facing the explosion
- the effect of seabed-borne vibrations propagating through the bedrock into the structure, in exactly the same way as on dry land.

The result of both of these effects is to cause the structure to vibrate at its natural frequency. The vibration causes shear forces in the structure which, if excessive, cause damage. It has been determined that the damage to massive structures on land is dependent on the maximum vertical velocity measured in the structure. Various maximum limits have been suggested (see Section 7.1.4).

For massive structures with low resonant frequency, the maximum velocity of the structure induced by the waterborne pressure waves may be estimated as:

$$V_m = \frac{2I_T}{\rho t} \tag{6.6}$$

where V_m is the peak velocity
ρ is the density of the structural material
t is the wall thickness of the structure facing the blast.

The doubling of impulse arises from the fact that the pressure of the shock wave is doubled at the surface of the structure. The maximum extra velocity induced at depth d on the structure by the water-borne wave is thus:

$$V_m = I_D\left(\frac{4\alpha dh}{Rm}\right) \tag{6.7}$$

where R is the range to the charge.

The greatest effect is thus at the maximum depth, because the impulse is the highest there. The effect of the waterborne shock wave is therefore minimised in tidal regions when explosives operations are carried out at low water.

When calculating charge sizes, the velocity resulting from the ground-borne vibration and the velocity due to the waterborne shock wave are assumed to be additive, and the charge size is calculated accordingly, using the method and criteria of Section 7.1.3.

Where there is any doubt as to the integrity of the structure, the use of trial charges in conjunction with recordings of vertical velocity, as detailed in Section 7.1.3 should be considered.

6.5.2 Flexible thin structures

It is difficult to estimate how underwater pressure waves from explosions are likely to affect floating or submerged elastic structures (such as ships or pontoons), chiefly due to the complexity of their construction, but:

- *at low frequencies*, large-scale bending of the entire structure may occur, with amplitudes controlled primarily by the impulse of the shock wave
- *at high frequencies*, individual plates or hull members can resonate at levels determined chiefly by peak pressure
- *at intermediate frequencies*, the response of the structure depends upon specific features of the total pressure waveform and is particularly difficult to predict
- there is the added complication that equipment on a ship (eg transponders, computers, corroded pipework) may be more susceptible to blast pressure waves than the ship's structure itself.

As a guide, it has been determined by a limited number of trials that an empirical rule for stand-off distances between conventional ships and underwater explosions is given by:

$$R_m = 24\sqrt{W} \tag{6.8}$$

where R_m is the stand-off distance (in m)
W is the charge weight (in kg).

Until more conclusive evidence is available, it is suggested that this, with an appropriate safety factor applied, should be adopted as a minimum stand-off distance for ships. However, it makes no allowance for the enhanced effects brought about by the complex reflected waveform of a large detonation in deep water, and a more sophisticated analysis is necessary in major explosives operations.

6.6 SEISMIC OPERATIONS

Seismic survey operations offshore use air gun explosions as a source of sound in order to form an image of underlying rock strata. The 'blast' is generated by abruptly venting a cylinder under water. Typically, an array containing a large number of air guns is towed behind a survey vessel at a depth of 10—20 m and, by controlling the delay between firing individual air guns, the blast may be focused or otherwise modified for optimum results.

Air gun blasts contain a high level of low frequency sound at 20–80 Hz as a result of the oscillation of the air bubble formed by the release of the high pressure air. An initial high peak in the sound pressure also occurs at the time the air is vented. A typical 4000 in^3 air gun might generate a pressure expressed as 4 MPa-m, ie a peak pressure level of 4 MPa (40 bar) at a range of 1 m. This level is reduced by distance in much the same way as is discussed for blast of high explosives in Section 6.2.1.

There are two ways in which swimmers or divers may be injured near seismic operations:

- There is potential for lung damage as the peak in the low frequency sound is at the resonant frequency of the submerged human thorax. Because low frequency sound decays rapidly in shallow water, it is likely that this effect is of most significance in deep water.
- Divers may also suffer hearing damage from the pressure in the initial peak, which is significant even at large ranges. However, recent research(6.8) indicates that human hearing is at least 28 dB less sensitive in water than in air when the ear is 'wet' (eg for swimmers and SCUBA divers). On this basis, peak pressures of up to 190 dB might be tolerable. At these levels though, there is considerable potential for hazard through unaware divers being startled but this risk may be reduced by ensuring that all divers and swimmers in the vicinity of seismic operations are aware of what is happening.

Both of these comments should be qualified by noting that seismic operations usually involve repetitive firing, and hence the possibility arises of injury accumulating over a period of time.

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7. Ground vibration and air blast

7.1 GROUND VIBRATION

7.1.1 Introduction

An explosive detonated in a borehole or within water produces pressure waves in the surrounding material. As the pressure waves propagate and travel away from the source, they form seismic waves, ie vibration waves. Two basic wave types are generated:

- *body waves* which propagate through the body of a medium, solid or liquid
- *surface waves* which propagate along the surface of the medium. They are produced when a body wave travels to the surface and is reflected back into the medium; the disruption of the surface by the reflection of the body waves creates the surface wave.

7.1.2 Parameters

Four terms are used to measure the magnitude of vibration waves. They are based on elastic wave theory and are related to the movement of the particles within the transmitting medium:

- *Displacement* – the distance that the particles move when they are oscillating, usually a small fraction of a millimetre.
- *Velocity* – how fast the particles move when they are oscillating. Because their velocity is continually changing, the peak or maximum velocity is the useful value. Peak particle velocity is expressed in mm/s.
- *Acceleration* – the rate at which the particle velocity changes during oscillation, usually expressed in mm/s^2 or in terms of g (the acceleration imparted to an object by the earth's gravitation pull).
- *Frequency* – the number of oscillations per second that a particle undergoes under the influence of the vibration wave, expressed as cycles per second, ie Hertz. Different types of seismic waves have different characteristic frequencies, depending on many factors. The frequency range of concern for vibration damage from blast-induced vibration is normally between 5 and 100 Hz.

A typical seismogram or vibration record is shown in Figure 7.1. Three traces are made to measure the particle movement in three mutually perpendicular directions:

- *longitudinal* – back and forth particle movement in the same direction that the vibration wave is travelling
- *vertical* – up and down particle movement perpendicular to the direction the vibration wave is travelling
- *transverse* – left and right particle movement perpendicular to the direction the vibration wave is travelling.

Because of the physical properties of water, the transverse, or shear, wave cannot be transmitted by water. The longitudinal (or compressive) wave is the most readily transmitted in this medium.

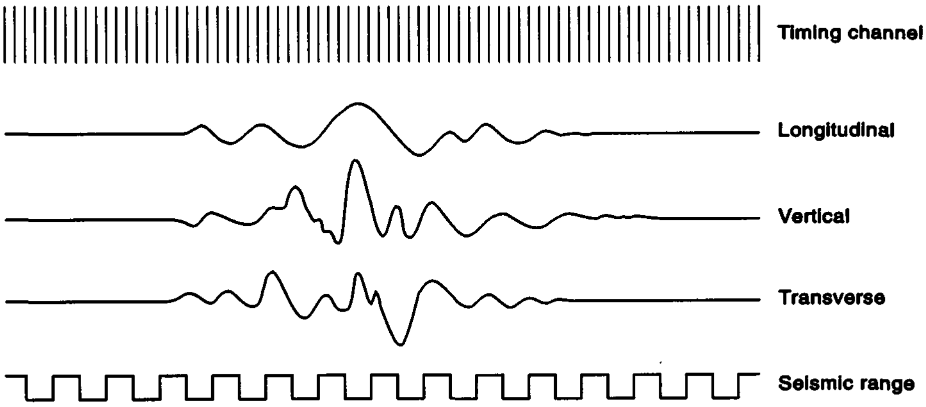

Figure 7.1 *Typical seismogram showing about 1 second of record length*

The seismogram could be recording particle displacement, velocity or acceleration, depending on the type of seismograph used to make the record. All three components – longitudinal, vertical and transverse – are necessary to completely describe the vibration intensity because the particles are oscillating in three-dimensional space.

For sinusoidal vibration (ie simple harmonic motion) displacement, peak particle velocity and acceleration are inter-related as follows:

$$V = 2\pi f A \quad \text{and} \quad a = 2\pi f V \tag{7.1}$$

where a = acceleration
V = particle velocity
f = frequency
A = displacement.

Therefore, if V and f have been measured by a seismograph, either acceleration or amplitude could be obtained within the limitations of assuming simple harmonic motion for the specific vibration event.

Much research, mainly by Langefors and Kihlstrom(7.1), Edwards and Northwood(7.2), and the US Bureau of Mines(7.3) has suggested that particle velocity is the parameter that correlates well with structural damage. USBM also suggests that measurements should be made in all three mutually perpendicular directions (see above), which is in line with ISO(7.4) and BSI(7.5) recommendations. Other BSs(7.6, 7.7) indicate the effects of blasting on buildings and their occupants. Specific problems may occur from underwater blasting in coastal regions. For example, most harbours are created at least partly by excavation and fill techniques. Thus there are substantial areas of reclaimed land in the immediate vicinity of blasting operations. Vibration transmission characteristics of fill material, particularly if recently placed, vary considerably. The frequency of the vibration is usually lower and can be in the region of between 3 and 10 Hz. With such low frequencies other parameters, eg displacement or acceleration, may also have to be considered.

Magnitude of waveforms at a given location depend largely upon geological conditions and blast design. In particular, the proportions of energy transmitted through the water and through the underlying ground are most dependent on whether charges are buried in the seabed, detonated at some point mid-water or placed on the seabed. A charge on the seabed releases about ten times as much energy into the water as a similar-sized charge in a drilled hole beneath the seabed.

7.1.3 Scaled distance

When explosives operations are planned to take place relatively close to inhabited properties or to vibration-sensitive structures and services, it is essential that accurate predictions are made well beforehand of the actual vibration levels to be generated at the structures. Working 'blind' could mean:

- very high complaint levels
- the possibility of damage
- late changes in the method of working, affecting production and economics.

Thus, whatever the explosives operation – harbour works, open pit, tunnel, trench, etc – there are great advantages to be gained from a vibration survey. Advanced planning is possible once the vibrational effects of the local geological conditions and water body have been ascertained.

Prediction of likely vibration levels at some distance from an explosive charge is possible by the 'scaled distance' approach. The method is based on the use of small trial charges placed in the material to be removed. The exact amount of explosives used would be determined by local conditions and the distance to the nearest structures of interest.

Figure 7.2 illustrates a typical application where underwater excavation is being planned in a harbour area bounded by a pier, a harbour wall and properties. A series of holes is drilled for small explosive charges, of a size that will not cause damage or excessive complaint. The possibility of any delicate equipment, electrical switchgear or computers nearby should also be investigated. For example, the blast may consist of 10 holes, each charged with 5 kg of explosive, giving a total charge of 50 kg. Each hole is detonated on a separate number short-delay detonator and therefore the maximum instantaneous charge is 5 kg. For vibration control it is this value which is of prime importance and needs to be known accurately.

A number of seismograms are needed, either in lines across the site in the directions of interest or at specific vibration-sensitive locations. In either case they should be located to give a reasonable range of expected peak particle velocities and their distances from the explosion should be measured accurately.

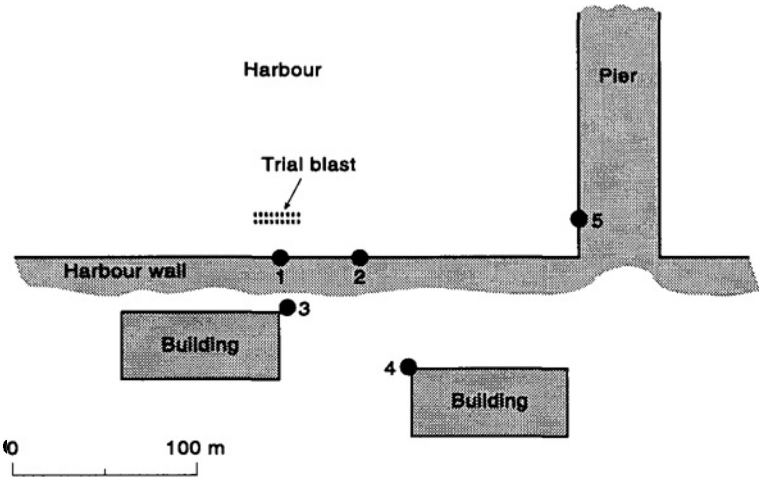

Figure 7.2 *Typical excavation area*

The vibration records obtained after firing should be analysed for the maximum particle velocity values in each vibration plane, the overall maxima being noted and tabulated in a manner similar to that shown in Table 7.1. The table also lists a scaled distance value, S, for each location, where:

$$S = \frac{D}{\sqrt{C_{mi}}} \quad (\mathrm{m/kg^{1/2}}) \qquad (7.2)$$

where S = scaled distance
D = distance from blast to recorder (in m)
C_{mi} = maximum instantaneous charge (in kg), ie the maximum weight of explosive on any one delay number.

Table 7.1 *Scaled distance data*

Blast No. 1
Maximum instantaneous charge 5 kg

Location No	Distance (m)	Scaled distance ($\mathrm{m/kg^{1/2}}$)	Maximum peak particle velocity (mm/s)
1	18.3	8.2	95.1
2	36.2	16.2	38.7
3	51.0	22.8	9.4
4	99.7	44.6	4.1
5	152.0	68.0	2.4

The maximum peak particle velocities are then plotted against their respective scaled distances. Log-log paper is generally used, to give straight line plots. The results of Table 7.1 together with another set of results are shown plotted in Figure 7.3. The further set of results from a second blast is usually essential. They can be either along the same general directions as the first line and hence produce a more accurate plot by means of more data points or, if necessary, in different directions, perhaps towards a further area of interest to check that the water and geological effects are the same in all directions.

A regression line is fitted to the data by means of a least squares analysis. This is the solid line in Figure 7.3 and represents the best-fit straight line through the data, showing how vibration magnitude changes as distance and maximum instantaneous charge weights vary. This line can be used in conjunction with Equations 7.1 to determine the most likely vibration values for a given maximum instantaneous charge weight at a given distance or, alternatively, the most likely maximum instantaneous charge weight of explosive to produce a given vibration level at a given distance.

However, in many cases, 'most likely' values do not offer adequate safeguard. What is usually required is a high level of confidence that the intended size of charge will not result in a certain vibration level being exceeded. This degree of confidence is generally taken as the upper 95% level and the necessary statistical calculations have been undertaken on the example data to give

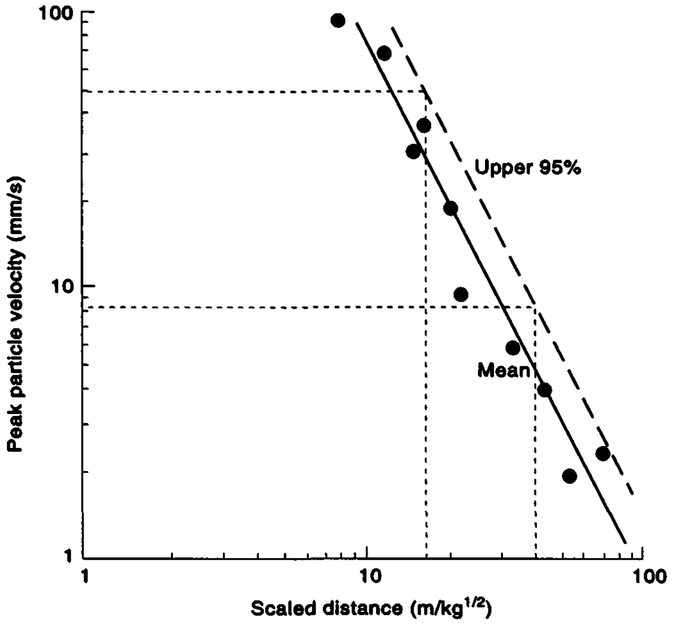

Figure 7.3 *Plot of peak particle velocities against scaled distances*

the dashed line in Figure 7.3. This line, parallel to the best-fit or mean line, may now be used for prediction purposes with the assurance that, statistically, less than 2.5% of data will be expected to plot above the line.

For example, at a distance of 90 m from a maximum instantaneous charge of 5 kg, the scaled distance value is $90/\sqrt{5}$ or 40.2 m/kg$^{1/2}$. Figure 7.3 shows that this represents a vibration level of 8.4 mm/s at the 95% confidence level (dotted line). Alternatively, given a vibration limit of 50 mm/s, the corresponding scaled distance value is seen to be 16 m/kg$^{1/2}$ at the 95% level. This gives rise to allowable instantaneous charges of, for example, 9.8 kg at 50 m or 2.4 kg at 25 m.

Data scatter

A certain amount of data scatter is to be expected when plotting vibration results as in Figure 7.3. There are many practical reasons why this is so, but it is acceptable provided the scatter is relatively small. When plotted data falls significantly wide of the regression line it is worthwhile attempting to discover why. If one vibration velocity as plotted is very much larger than expected it is clearly worth investigation in order to preclude a further occurrence. If the value is rather lower than expected it is also worth investigation, because it may be possible that other vibration levels can be similarly reduced.

Changes in geological conditions and water depth across the blasting area or between the receiver and source can have a significant effect on vibration velocities and may make it necessary to repeat the scaled distance monitoring when conditions are known to have changed.

7.1.4 Vibration criteria

BS 7385: 1993 Evaluation and Measurement for Vibration in Buildings. Part 2: Guide to Damage Levels from Groundborne Vibration(7.6) recommends guide values for peak particle velocities below which cosmetic damage should not occur. Figure 7.4 is taken from the BS. The criteria reflect the greater likelihood of damage to 'light' buildings from vibrational disturbances with lower frequency contents. At frequencies less than 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded in light buildings. Acceptable peak velocity levels may be higher for very massive harbour walls; the specific characteristics of each structure and vibration source should be considered individually.

It is not unusual for structures adjacent to the site of explosives operations to house relatively delicate machinery or equipment. In this case acceleration may be the limiting vibration parameter, and professional advice is often essential in order to arrive at realistic vibration limits.

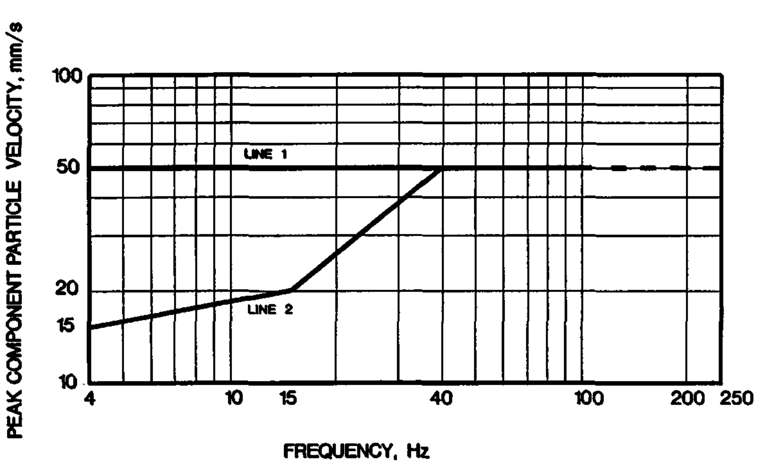

Figure 7.4 *BS blasting criteria – peak particle velocities that should prevent cosmetic damage in buildings*

Line 1 Reinforced or framed industrial and heavy commercial buildings
Line 2 Residential or light framed buildings
Source: BS 7875: 1993(7.6)

7.2 AIR OVERPRESSURE

7.2.1 Introduction

Airborne waves are invariably generated by explosions, even underwater explosions. These waves cause air overpressure containing energy over a wide range of frequencies, some of which is audible (sound or noise waves), but most of which is at frequencies below the audible range (ie less than 20 Hz) and known as concussion.

As the airborne wave passes, the pressure of the air at a point rises rapidly above ambient pressure and then falls more slowly to a value below ambient before returning to ambient after several oscillations about it.

Damage may occur when the maximum pressure in the wave (the peak air overpressure) is excessive. This value can be measured as pressure (Pa, bar or psi) or in decibels (dB). Such a decibel scale indicates a linear or flat response and should not be confused with the dB(A) scale used in the measurement of pure noise.

7.2.2 Overpressure criteria

Considerable research at the United States Bureau of Mines(7.8) has produced levels of peak air overpressure which are likely to cause damage and has led to recommendations of maximum levels. The recommended maxima are based on the minimal probability of the most superficial type of damage in residential properties and vary according to instrument response:

Instrument response	*Maximum level*	
0.1 Hz high-pass	134 dB re 20 μPa	0.0159 psi
2.0 Hz high-pass	133 dB	0.0141 psi
5.0 or 6.0 Hz high-pass	129 dB	0.0089 psi
C – slow	105 dBC	0.0089 psi

Peaks of over 135 dB(lin) re 20 μPa can cause irreversible ear damage. Exposure of staff or public to these levels should be avoided.

7.2.3 Minimising air overpressure

Although air overpressure is relatively difficult to control because of its variability within the atmosphere, much can be done to reduce its magnitude at source and hence its likely effect on nearby property, even under unfavourable conditions.

A well-designed blast with all explosive adequately confined is essential to minimise air overpressure. Significant air overpressure readings are most likely to occur from plaster or surface type blasting in shallow water. This may be a strong influencing factor in a decision to carry out the blasting by drilling rather than surface blasting in areas close to residential zones.

In explosives operations under water, the depth of water cover plays a major role in determining air overpressure levels. This is especially true for lay-on charges where the gas bubble may break surface without an adequate cover, giving rise to relatively high air overpressure levels. Thus, the use of unconfined charges should be avoided whenever possible. Drilled holes or mechanical breakage should be employed instead. The use of surface lines of detonating cord should also be avoided if possible and, when unavoidable, they should be kept to the absolute minimum and covered with at least 600 mm of a dense material.

7.2.4 Statutory requirements

In the United Kingdom, the *Control of Pollution Act 1974* gives local authorities the power to determine the way in which temporary works such as underwater blasting are conducted in order to minimise the effects of noise in the local community. Notices may be issued to specify the conditions and hours within which plant may be operated or explosives fired. Where appropriate, maximum permitted noise levels may be set, and monitored during the operation. It is essential that an explosives contractor contacts the Environmental Health Department of the local authority so that any requirements are agreed well in advance of the blasting operation. The authority is required under the *Act* to reply to an application within 28 days.

7.3 INSTRUMENTATION AND MEASUREMENT

7.3.1 Justification

In addition to their intended effects, shock waves from underwater explosions (see Section 6.1) may cause damage to nearby structures, swimmers, divers and fish, ie they may have structural, human or environmental effects. Each needs to be considered when designing a programme of blasting. Traditionally, damage to structures is the one that has received most attention but, increasingly, the environmental consequences of blasting must be considered. These can range from temporary reductions in fish catches to destruction of an entire local fish stock.

In most underwater blasting operations, it is of considerable importance to make underwater measurements, both to reassure concerned parties that attention is being paid to the unwanted effects of blasting and to demonstrate, in the event of a claim or complaint, that levels were kept within recognised limits. Also, before the start of any out-of-the-ordinary blasting operations, measurements on a trial basis may be of value in determining what charge weights to use for the main operation (see Section 7.1.3).

7.3.2 Instrumentation

The short duration of a blast event and the high frequencies associated with the ground motion restrict the type of instrumentation that can be used to monitor ground vibration but a wide range of transducers and associated equipment is commercially available. Pressure is measured with transducers often referred to as hydrophones. Acceleration or velocity are normally measured by means of accelerometers – several waterproof types are on the market. Signals from any of these transducers are usually pre-amplified at an above-water location before being recorded.

Transducers are generally the weakest link in the measurement system because they translate the mechanical motions into electrical signals. They must be capable of withstanding the anticipated hydrostatic and blast pressure while maintaining accuracy. Hydrophones are available that can take substantial pressures without damage.

The transducers used are very specialised, eg solid state or tourmaline piezoelectric pressure transducers. The main characteristics of a hydrophone that affect its performance are:

- *sensitivity* – the ratio of its electrical output to its mechanical displacement or velocity. Sensitivity is established by the transducer manufacturer, and details of it (the transducer's calibration) are provided with a new instrument. It is usually quoted in two ways – volts produced per pascal or bar of applied pressure (voltage sensitivity), or picocoulombs of charge per pascal of pressure (charge sensitivity).
- *frequency response* – the frequency range over which the electrical output is constant with a constant mechanical motion. A flat frequency response from 10 Hz to at least 10 kHz is required.
- *environmental sensitivity* – the response of the transducer to humidity, temperature or acoustic noise (relevant because these instruments are required to perform in a relatively harsh field environment)
- *mass and size* – the low-frequency sensitivity of a velocity transducer increases proportionally with the mass of the transducer but, although a large transducer may be more

sensitive at low frequencies, it may be more difficult to install and may change the characteristics of the system monitored.

The method of attaching transducers to surfaces is dependent on the acceleration levels that are expected from the vibrations to be monitored:

- When the maximum accelerations are less than 0.3*g*, there is little possibility of rocking the transducer or the transducer package, and the type of mounting is not critical. Under these circumstances, transducers may simply be placed on a horizontal measurement surface with no special holding device.
- When the maximum particle accelerations fall between 0.3*g* and 1.0*g* and the measurement surface is soil, the transducer should be completely buried or partially buried and sandbagged. When the measurement surface consists of rock, asphalt or concrete, the transducer should be fastened down with double-sided tape, epoxy adhesive or quick-setting cement.
- When the maximum accelerations exceed 1.0*g*, only adhesive, cement or bolts are sufficient to hold the transducer to a hard surface. In soil, complete burial is necessary to provide a sufficient retaining force.

The signal from a transducer must be conditioned, ie it must be amplified to raise the relatively low level output to a level where it may be recorded by the associated equipment. Fundamentally, there are two sorts of amplifiers:

- *voltage amplifiers* – simply convert the low voltage to a proportionately higher one. They are simple and inexpensive, but suffer from a tendency to pick up electrical noise from their surroundings. They also reduce the high frequency sensitivity of the transducer when the cable from the transducer is long.
- *charge amplifiers* – measure the current from the transducer, rather than the voltage, but still provide an output voltage to feed the recording equipment. Their construction is more complex than voltage amplifiers but they overcome the loss of sensitivity with long connection cables.

In both cases, the amplifiers provide an output voltage proportional to pressure. The simplest amplifiers to use are those where the sensitivity of a hydrophone is dialled into the amplifier, enabling the amplifier output to be set at a convenient value, eg one volt per bar or one mV per Pa. Subsequent analysis is then easier. Without this, the sensitivity of the hydrophone has to be taken into account when measurements are analysed.

It is important to ensure reliable operation of all instrumentation equipment used in the harsh environment of a blasting operation. As a safeguard, some duplication of equipment may be necessary to ensure accurate recordings even if some equipment malfunctions.

7.3.3 Underwater measurement

All the physical features of the whole instrumentation system should be recorded as part of a scheme of underwater measurement, eg position of the transducers, instrument types and serial numbers, time, etc.

Measurements can be made on floating or fixed structures. The parameters measured can be velocity (in the range 0–200 mm/s), acceleration (0–50*g* with a 100*g* shock capability) or pressure (0–13 MPa). Pressure can be measured either as hydrostatic or pulse pressure and pressure measurements can be made down to 300 m, with acceleration measurements down to 200 m depth.

Two parameters of the recorded blast wave are of interest:

- *peak overpressure* of the blast – the maximum pressure above ambient reached by the wave
- *impulse* of the wave – technically the peak level of the integral of the pressure (as detailed in Section 6.2.3) but often estimated by calculating the area (in pascal.seconds) under the initial peak of the wave.

Hydrophones can be used to measure the impinging pulse pressure from a blast on a structure such as a ship's hull, together with measuring the velocity and acceleration on critical areas such as stern tubes, engine mountings and hull plates.

By using hydrophones at various depths in the water, the decay of pressure with distance can be calculated for various charge weights detonated in free water or beneath the seabed. Shock waves can be affected by surface and bottom reflections and the depth of water (see Chapter 6).

Waveforms from hydrophones must be recorded (via the conditioning amplifier) for subsequent inspection, analysis and archiving. The blast wave from an underwater explosion typically lasts only a few milliseconds. Recording is essential in order that important parameters such as peak overpressures and impulse can be post-processed. Wherever possible, outputs should be recorded on tape or digital data-logging equipment. Recordings of this type have the advantage that they can be post-analysed in various ways – eg to yield peak pressure, impulse and frequency spectrums from a single recording of blast pressure. Some attention should be given to the bandwidth of the recording; a frequency response of at least 10 Hz to 100 kHz may be necessary to minimise distortion of the recording.

Analysis of the data may take many forms but, as a minimum, it is suggested that schedules are kept of peak blast pressure against details of charge weight, range, times, etc, and compared with any limits that have been set for blast pressures. Any incident of damage can be investigated against the tabulated values of pressure.

Vibration measuring under water is a complex subject and expert advice should be taken.

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8. First aid and management of blast injury

8.1 INTRODUCTION

Whenever explosives are employed in diving operations there is always a risk to personnel of accidental or premature detonation, either at the surface or under water. While the mechanisms involved in blast-produced injury are basically similar in both situations, the differences in density of air and water modify the pattern of injury.

For effective first-aid treatment of blast casualties an awareness of the type of injury to be expected is vital; there may be late manifestations of internal injury which, if overlooked, may pose a threat to survival. Because the latent internal injuries to be expected from air blast and underwater blast may differ significantly, a general appreciation of the different pressure waves produced (as discussed in Section 6.1) will provide a guide to effective casualty management.

8.2 BLAST INJURY

8.2.1 In-air explosions

The injury effects of blasts in air are customarily divided into:

- *primary* – resulting from variations in local pressure
- *secondary* – associated with the impact of debris energised by blast, shock wave, blast winds and often gravity
- *tertiary* – resulting from gross bodily displacement (ie 'translation')
- *indirect* – eg injuries resulting from fires and noxious gases.

Primary effects

Typically, damage resulting from sudden variation in ambient pressure produces lesions at or near the interface between tissues of different densities. Air-containing organs (such as the lungs) the gastro-intestinal tract (the gut), the middle ear and sinuses are especially affected. The mechanism of the injuries is still a matter for speculation but contributing factors undoubtedly include the difference in velocity of the shock wave in the tissues (around 1450 m/s) and in the contained air or gas (around 340 m/s), and the vastly greater compressibility of the latter.

In the lungs there may be massive haemorrhage, rupture of the lung sacs and collections of air beneath the pleura (the membrane which covers the lung surface). Air escapes into the circulation and may travel to the heart and thence to various organs, leading to air embolism. Air embolism in the brain is the most likely cause of symptoms of brain haemorrhage, which may be present in blast victims who have no external injuries. Air embolism within the coronary arterial system leads to oxygen starvation of the heart and perhaps to heart failure.

Late deaths may result from lung insufficiency, partly the result of direct damage to the lungs from the overpressure and from haemorrhage and partly the result of multiple small areas of embolism within the lungs, leading to pulmonary oedema (fluid on the lungs).

Rupture and perforation of the gut is more typical in underwater blast injury than in blast injury from in-air explosions.

Secondary effects

Missiles produce a variety of injuries, including contusions (bruises), lacerations, penetrating wounds and fractures. Small fragments travelling at very high speeds penetrate deeply, and a very small entry wound may be associated with severe injury to blood vessels and internal organs. A careful search should be made for such wounds and appropriate action taken.

Tertiary effects

The injuries that these cause (fractures, multiple injuries) are self-evident and first aid is on standard principles.

8.2.2 Underwater explosions

The injury potential of underwater blast can be related to the physical phenomena of underwater explosions as itemised in Section 6.1.3. As a rule all the components are present, and from the point of view of casualty management the distinctions are largely academic but, in order to minimise the risk to divers and swimmers where there is a potential hazard from the use of underwater charges (or in salvage operations involving handling of explosive ordnance or cutting into compartments which may contain explosive gases), an appreciation of the contributions from the different components may enable useful advice to be given.

Shock wave and bubble pulse injuries

The characteristic of shock wave and bubble pulse injury is haemorrhage into and rupture of air-containing organs. Lung damage is a constant feature. Small perforations of the large bowel (and less frequently the small intestine) may occur and there may be areas of haemorrhage beneath the outer coat of the intestine which will lead to delayed perforation in the course of a few days.

'Solid' tissues, such as bone, muscle and fat, can tolerate very high shock wave pressures without significant injury. Experimental exposures of a limb to the 7 MPa (1000 lb/in^2) shock wave from a small charge at close range results in a strong stinging sensation, but no damage. The shock wave travels through the water and traverses the limb without impediment. However, animal experiments indicate that shock waves can directly damage brain tissue; CNS (central nervous system) symptoms cannot always be attributed to air embolism.

Close to the explosive source there is violent trauma to the rib-cage, chest and abdominal contents, and limb fractures. Involvement in the turbulence associated with the bubble pulse results in gross injury, including major lacerations and avulsion (tearing off) of tissues and limbs.

Water movement ('water-ram effect') injuries

If an animal is protected by a shock-absorbing screen which reduces the shock wave well below the lethal level, severe injury and death may nevertheless result. Indeed the sound-absorbing screen contributes to the severity of the injury – which results from the water-ram effect. ('Body armour' behaves in the same way.)

Typically there is contusion and haemorrhage of the lung bases and corresponding damage to the upper surface of the liver, consistent with the abdominal contents being forced violently up into the chest. Organs of different densities may be displaced differentially, resulting in tearing of attachments (eg damage to the suspensory ligament of the gall bladder or a linear tear of the liver along its line of attachment).

8.3 BLAST CASUALTIES

8.3.1 Primary care – first aid for laymen, paramedics and nurses

In order to provide effective first aid for this specialised type of injury it is essential that the first aider should have a clear understanding of the nature of the basic problem. Those who are likely to be called upon to provide first aid to underwater blast survivors should be fully familiar with all the contents of this chapter.

In general terms, the effect of blast is likely to be more severe in air-containing parts of the body than in solid tissue. The lungs and the gut are thus more likely to sustain some degree of damage, but the serious effects may not become manifest until an interval of time has elapsed. The central nervous system is also frequently affected, but it is not entirely clear whether this is due to the primary effect of blast on the brain or secondary to air embolism from damaged lungs. No matter how trivial injury seems at first, it is essential that a medical opinion be obtained as soon as possible after immediate care has started. Arrangements should also be made for the casualty to be transferred to hospital as soon as possible.

Examination

The immediate priority is to establish that the casualty is conscious, that his airway is not obstructed, that he is breathing and that his heart is functioning. Appropriate resuscitation should be started if there is any doubt about the airway and breathing.

A complete examination should next be undertaken. It should be conducted from head to toe being careful to feel:

- behind the head and neck for evidence of swelling or bleeding
- behind the part of the body upon which the casualty is lying.

Part of the examination should include the passage of a hand over the abdomen to determine whether there is tenderness or any feeling of undue rigidity.

When the examination is complete, the pulse rate, respiration rate and level of consciousness should be measured, and repeated at 30 minute intervals until medical help arrives. They will provide important evidence of deterioration and they will also be of great value to medical practitioners if the casualty's condition changes.

A record of the results of each examination should be kept.

Position

If the casualty is unconscious he should be placed in the 'recovery position' (see Figure 8.1). If there is no particular contra-indication, the left lateral position is probably better than the right, ie right hip uppermost so that the left side of his chest is in contact with the ground. He can be placed slightly head down on a stretcher in order to minimise the passage of air bubbles into the brain or the coronary circulation. However, this should only be done if there is no evidence of respiratory distress.

If the subject is conscious, he is probably also best placed slightly head down in the left lateral position for the same reason. If there is an injury to one side of the chest rather than the other, he should lie on the injured side to allow maximum use to be made of the uninjured lung. Whatever position he is in, strict rest should be observed and he should be strongly reassured, since both physical and psychological rest are important at this stage of his management.

If there is respiratory distress, breathlessness or cyanosis (a bluish appearance), it is probably best for the casualty to be propped in a sitting position because this will allow the gut to fall away and thus increase the efficiency of his lungs in transferring oxygen. A casualty with an obvious chest injury and any degree of respiratory distress should thus be sat up leaning towards the injured side.

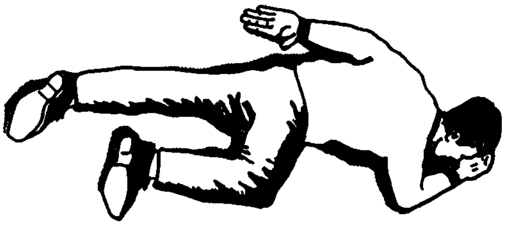

Figure 8.1 *Unconscious blast casualty in the 'recovery position'*

Ventilation

If breathing has ceased or is inadequate, it will be necessary to administer artificial respiration until breathing does become adequate. It is probably better carried out mouth-to-mouth, rather than by the use of a mechanical resuscitator, since it has been suggested that such equipment and certainly positive pressure respirators could be responsible for inducing or adding to air embolism via lacerations of lung tissue. On the other hand, if oxygen is available it should be administered where possible in all cases of respiratory distress – at a flow rate of around 15 litres per minute. This should improve the diffusion of oxygen across damaged lung and minimise the effect of gas embolism should it occur.

Administration of fluids

Fluids should be administered with great caution, since there is always the likelihood of serious intra-abdominal catastrophe developing at any time. Fluids by mouth should therefore be severely restricted, but a sip of water can be administered if coughing develops, since coughing should be kept to a minimum to prevent pressure increases within the lungs.

Intravenous fluids should also be administered with great caution because of the inevitable damage to the lungs. Overloading of the circulation will make any lung lesion worse. On the other hand, if there is a complaint of severe abdominal pain and if there is evidence of deterioration in the casualty, such as the signs of shock developing or the pulse rate increasing, it would be reasonable to establish an intravenous route if the first aider has the facilities and necessary training. This would act as a safeguard against sudden collapse when it might be difficult to establish an intravenous route. If intravenous infusion is established as a precautionary measure, the rate of infusion should be around 0.5 litre of dextrose or ringer lactate over 8–10 hours.

Other treatment

It may be necessary to conduct other routine first-aid manoeuvres, such as arresting bleeding, immobilising a fracture or applying a dressing to an open wound, but these manoeuvres conform to standard first-aid procedures; the special provisions for managing blast injury are those referred to above.

Equipment and training

The contents of a standard diving support first-aid kit should be sufficient to treat underwater blast injuries and such kits should be available anywhere that underwater explosives operations are taking place.

The first-aid training which would ensure an adequate immediate response to underwater blast injuries can best be obtained from those centres which specialise in the training of immediate care for the offshore industry.

8.3.2 Primary care – first aid for doctors

There are few principles which are different for doctors than for first aiders. The doctor equally needs to have a clear understanding of the problem. He may be able to do more for the casualty because he may have additional skills such as the ability to intubate the pleural cavity or the trachea if he feels that to be necessary. He is also in a position to determine whether drugs should be used to depress the coughing reflex but would require to balance this against the depression of the respiratory centre which takes place when narcotics are used. He should also consider early administration of an antibiotic to prevent the development of pneumonia or other infection and whether an intravenous cardiac glycoside should be used if there is evidence of heart failure from coronary arterial air embolism.

The use of hyperbaric oxygen has been advocated for the management of lung lesion in blast-induced air embolism. This would seem more sensible than the use of positive pressure ventilation. There is almost certain to be a recompression facility close to diving operations and thus hyperbaric oxygen should be considered in cases of blast injury where there is lung or central nervous system involvement.

8.3.3 The clinical picture

It is apparent from Section 8.2 that blast casualties may exhibit the entire range of traumatic injuries, including burns and pulmonary damage from noxious gases, and in every degree of severity. Less obvious may be primary blast damage to the lungs and abdominal organs which, if not recognised early, may severely compromise recovery.

In the absence of obvious gross trauma, a frequent finding in casualties who succumb within 30 minutes is the presence of air emboli in coronary, cerebral and mesenteric arteries. Later deaths are generally associated with pulmonary oedema and severe anoxia.

Surviving patients without evidence of external injury may complain of retrosternal pain and dyspnoea. Clinical signs include tachypnoea, cyanosis and particularly haemoptysis. In practice however, associated severe injuries, particularly of the intra-abdominal organs, usually distract attention of the examiner away from the chest.

Survivors of underwater blast often give a history of sudden severe abdominal pain, sometimes likened to a violent kick in the stomach. Explosives with high velocities of detonation may induce a stinging pain in the chest and head; slower detonating explosives are felt as a solid thump in the chest and abdomen. Either may be associated with significant lung injury.

A pain in the right shoulder may indicate injury in the area of the gall bladder, including laceration of the liver. Nausea, vomiting and an urge to defecate are common sensations, sometimes with testicular pain. There is often transient paralysis of the lower limbs.

The high incidence of abdominal injury in underwater blast injuries makes it mandatory to obtain a surgical opinion as early as possible. Laparotomy will almost always be required where there are acute abdominal symptoms, despite the likelihood of lung damage which will tend to complicate the anaesthesia. However, experience of underwater blast injury in recent years has shown that surgical treatment of abdominal lesions can be undertaken with confidence.

Blast, even at very low overpressures, is always a threat to the hearing and a clinical audiogram should be performed to establish whether hearing has been damaged, its degree and nature. Three types of injury may be present:

- rupture of the tympanic membrane
- dislocation of the ossicles, with or without tympanic membrane rupture
- damage to the inner ear, which may resolve or may be permanent.

On auscultation, râles and rhonchi can usually be heard, particularly at the bases, but chest symptoms are often slight in the early stages and the physical signs unremarkable.

A pulse rate of up to 150 is the rule, but blood pressure is often within normal limits. A finding of lowered blood pressure is often attributed to loss of blood, but in blast injury it may be the result of emboli, vagal reflex or increased pressure in the pulmonary artery following extensive lung damage.

A chest X-ray is mandatory, and the radiological findings are often much more impressive than the clinical picture. Infiltration is almost always present. There may be pneumothorax, haemothorax or pneumomediastinum, and interstitial emphysema and subpleural emphysematous bullae may also be seen. At a later stage, there may be increasing evidence of consolidation with enlargement of the heart, but the majority of cases respond well to treatment and the X-ray signs resolve within a period of weeks.

X-ray investigation for evidence of perforation is also essential when there is suspected intra-abdominal injury.

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Bibliography

General

Blasters' Handbook
E I duPont de Nemours & Co (Inc), sixteenth edition, 1980

Blasting Practice
Nobel's Explosives Company Limited, fourth edition, 1972

BRITISH STANDARDS INSTITUTION
BS 6349: 1991 Code of Practice for Maritime Structures – Part 5 Code of Practice for Dredging and Land Reclamation
BSI, 1991

BRITISH STANDARDS INSTITUTION
BS 7765: 1994 Detonators for Civil Use
BSI, 1994

COLE, R H
Underwater Explosions
Princeton University Press, 1948, Dover Publications, Inc, New York, 1965

COOK, M A
The Science of High Explosives
Reinhold Publishing Corporation, 1958, 2nd printing 1959

COOK, M A
The Science of Industrial Explosives
IRECO Chemicals, 1974

Explosives Engineering
Journal of the Institute of Explosives Engineers, Straightline Publishing, Glasgow, quarterly
(Formerly *Explosives Engineer*)

FORDHAM, S
High Explosives and Propellants
Pergamon Press Ltd, 1966

GUSTAFSSON, R
Swedish Blasting Technique
SPI, Gothenburg, Sweden, 1973

JOHANSSON, C H and PERSSON, P A
Detonics of High Explosives
Academic Press, 1970

Propellants, Explosives, Pyrotechnics
VCH Verlagsgesellschaft mbH, Weinheim, Germany, bi-monthly
(Formerly *Propellants and Explosives*
Verlag Chemie GmbH, Weinheim)

Relevant UK Legislation

Explosives Act 1875

Explosives Act 1923

Explosive Substance 1942 No 1382

Explosive Substance, OSS 11C 1943 No 1252

Explosive Substance, OSS 11D 1944 No 139

The Compressed Acetylene Order 1947 No 805

Fireworks Act 1951

The Conveyance of Explosives Byelaws 1951 No 869

The Stores for Explosives Order 1951 No 1163

The Magazines for Explosives Order 1951 No 1164

The Stores for Explosives Order 1953 No 1197

The Visiting Forces (Application of Law) Order 1954 No 635

The Conveyance by Road of Government Explosives & Explosives of Visiting Forces Regulations 1956 No 1050

The Conveyance of Explosives Byelaws 1958 No 230

The Engineering Construction (Extension of Definitions) Regulations 1960 No 421

The Construction (General Provisions) Regulations 1961 No 1580

The Visiting Forces & International Headquarters (Application of Law) Order 1965 No 1536

The Ammonium Nitrate Mixtures Exemption Order 1967 No 1485

The Engineering Construction (Extension of Definitions) Regulations 1968 No 153

Mineral Workings (Offshore Installations) Act 1971

The Isles of Scilly (Explosives) Order 1971 No 969

The Building Standards (Scotland) Regulations 1971 No 1596

The Offshore Installations (Inspectors and Casualties) Regulations 1973 No 1842

Health and Safety at Work etc Act 1974

Merchant Shipping Act 1974

Control of Pollution Act 1974

The Explosives Act 1875 and 1923 etc (Repeals and Modifications) Regulations 1974 No 1885, as amended

The Health and Safety Licensing Appeals (Hearing Procedure) Rules 1974 No 2040

The Health and Safety Licensing Appeals (Hearing Procedure) (Scotland) Rules 1974 No 2068

The Explosives Act 1875 and 1923 etc (Repeals and Modifications) (Amendment) Regulations 1974 No 2166

Petroleum and Submarine Pipe-lines Act 1975

The Merchant Shipping (Diving Operations) Regulations 1975 No 116

Explosives (Age) of Purchase Act 1976

The Offshore Installations (Operational Safety Health and Welfare) Regulations 1976 No 1019

The Health and Safety (Enforcing Authority) Regulations 1977 No 746

The Conveyance by Rail of Military Explosives Regulations 1977 No 889

The Submarine Pipe-lines (Inspectors etc) Regulations 1977 No 835

The Compressed Acetylene (Importation) Regulations 1978 No 1723

The Explosives Act 1875 (Exemptions) Regulations 1979 No 1378

The Health and Safety (First Aid) Regulations 1981 No 917

First Aid at Work: Approved Code of Practice and Guidance, Health and Safety (First Aid) Regulations 1981, COP 42, 1990, HSE Books

The Diving Operations at Work Regulations 1981 No 399

The Merchant Shipping (Submersible Craft Construction and Survey) Regulations 1981 No 1098

The Classification and Labelling of Explosives Regulations 1983 No 1140

The Explosives Act 1875 etc (Metrication and Miscellaneous Amendment) Regulations 1984 No 510, as amended

The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985 No 2023

The Building Regulations 1985 No 1065

Consumer Protection Act 1987

The Dangerous Substances in Harbour Areas Regulations 1987 No 37

Approved Code of Practice under the Dangerous Substances in Harbour Areas Regulations 1987, COP 18

The Health and Safety (Explosives and Petroleum Fees) (Modification) Regulations 1987 No 52

The Quarries (Explosives) Regulations 1988 No 1930

Approved Code of Practice under the Quarries (Explosives) Regulations 1988, COP 27

The Docks Regulations 1988 No 1655

The Road Traffic (Carriage of Explosives) Regulations 1989 No 615

Approved Code of Practice under the Road Traffic (Carriage of Explosives) Regulations 1989, COP 36

The Health and Safety (Enforcing Authority) Regulations 1989 No 1903

The Diving Operations at Work (Amendment) Regulations 1990 No 996

The Control of Explosives Regulations 1991 No 1531

The Packaging of Explosives for Carriage Regulations 1991 No 2097

The Health and Safety (Fees) Regulations 1992 No 1752

The Diving Operations at Work (Amendment) Regulations 1992 No 608

The Offshore Installations (Safety Case) Regulations 1992 No 2885

The Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Goods) Regulations 1992 No 744

The Placing on the Market and Supervision of Transfers of Explosives Regulations 1993 No 2714 (implementing Directive 93/15/EEC 'The placing on the market of explosives for civil use Directive')

The Health and Safety at Work etc Act (Application outside Great Britain) Order 1995 No 263

The Marking of Plastic Explosive for Detection Regulations 199? (draft in circulation)

Guidance

HSE Guide to the Explosives Acts 1875 and 1923
Health and Safety Executive

Disposal of Explosives Waste and the Decontamination of Explosives Plant
Health and Safety Executive Guidance Booklet HS(G) 36, 1987

Memorandum for the Guidance of Applicants for a Licence for an Explosives Factory or Explosives Magazine
Health and Safety Executive Leaflet LP 49 (Out of print)

HSE Guidance to Factory and Magazine Licensees – Storage of Explosives: Security Arrangements
Health and Safety Executive (Out of print)

HSE Guide to the Classification and Labelling of Explosives Regulations 1983
Health and Safety Executive HS(R) 17

HSE Guide to the Control of Explosives Regulations 1991
Health and Safety Executive, L10

HSE Guide to the Packaging of Explosives for Carriage Regulations 1991
Health and Safety Executive, L13

HSE List of Authorised Explosives 1992: Explosives Acts 1875 and 1923
Health and Safety Executive, Rev 1992

International Maritime Dangerous Goods Code (IMDG)
International Maritime Organisation, 1992

HSE – Conditions for the Authorization of Explosives in Great Britain
Health and Safety Executive, HS(G)114, 1994

Classified and Authorised Explosives
Health and Safety Executive , 1994

HSE Guide to the Placing on the Market and Supervision of Transfers of Explosives Regulations 1993
Health and Safety Executive, L66, 1995

Copyrighted Materials
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References

Chapter 2 Planning, responsibilities and legislation

2.1 *Explosives Act 1875*
HMSO

2.2 *Explosives Act 1923*
HMSO

2.3 *Health and Safety at Work etc Act 1974*
HMSO

2.4 *The Health and Safety at Work etc Act 1974 (Application Outside Great Britain) Order 1995*
SI 1995 No 263, HMSO

2.5 *The Diving Operations at Work Regulations 1981*
SI 1981 No 399, HMSO

2.6 *The Merchant Shipping (Diving Operations) Regulations 1975*
SI 1975 No *116*, HMSO

Chapter 3 Transport and storage of explosives

3.1 *The Packaging of Explosives for Carriage Regulations 1991*
SI 1991 No 2097, HMSO

3.2 *The Classification and Labelling of Explosives Regulations 1983*
SI 1983 No 1140, HMSO

3.3 *A Guide to the Classification and Labelling of Explosives Regulations 1983*
HR(R) 17, HSE Books

3.4 *Explosives Act 1875*
HMSO

3.5 *Safety and Health at Work*
'The Robens Report', Cmnd 5034, 1972, HMSO

3.6 *Health and Safety at Work etc Act 1974*
HMSO

3.7 *Transport of Dangerous Goods* (the 'Orange Book')
The United Nations

3.8 *The Road Traffic (Carriage of Explosives) Regulations 1989*
SI 1989 No 615, HMSO

3.9 *The Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Goods) Regulations 1992*
SI 1992 No 744, HMSO

3.10 *The Placing on the Market and Supervision of Transfers of Explosives Regulations 1993*
SI 1993 No 2714, HMSO

3.11 *The Control of Explosives Regulations 1991*
SI 1992 No 1531, HMSO

3.12 *Approved Code of Practice under the Road Traffic (Carriage of Explosives) Regulations 1989*
COP 36, ISBN 0-11-885497-6, HSE Books

3.13 *The International Maritime Dangerous Goods Code*
Consolidated edition including Amendment 27, 1994, International Maritime Organisation

3.14 *The Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations 1990*
SI 1990 No 2605, HMSO

3.15 *The Dangerous Substances in Harbour Areas Regulations 1987*
SI 1987 No 37, ISBN 0-11-076037-9, HMSO

3.16 *Approved Code of Practice – Dangerous Substances in Harbour Areas*
COP 18, ISBN 0-11-883857-1, HSE Books

3.17 *The Air Navigation (Dangerous Goods) Regulations 1994*
SI 1994 No 3187, HMSO

3.18 *Technical Instructions for the Safe Transport of Dangerous Goods by Air*
International Civil Aviation Organization, Document 9284 – AN/905, 1995–1996 edition

3.19 *IATA Dangerous Goods Regulations*
International Air Transport Association, published annually, available from IATA,
2000 Peel Street, Montreal, Canada, H3A 2R4

3.20 *Memorandum for the Guidance of Applicants for a Licence for an Explosives Factory or Explosives Magazine*
HSE Leaflet LP49, HMSO

3.21 *Guide to the Explosives Acts 1875 and 1923*
Reprinted 1968, HSE Books

3.22 *Storage of Explosives: Security Arrangements*
Health and Safety Executive (Explosives Inspectorate)

3.23 *Security of Explosives Stores and Registered Premises*
Home Office Circular No 113 1972 (Available from HSE Explosives Inspectorate)

3.24 *The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995*
SI 1995 No 743, HMSO

Chapter 4 Operational precautions

4.1 INSTITUTE OF PETROLEUM
Recommended Practices for Radio Silence when Conducting Wireline Services Involving the Use of Explosives
John Wiley and Sons for The Institute of Petroleum, October 1984

4.2 BRITISH STANDARDS INSTITUTION
BS 6657:1986 Guide for Prevention of Inadvertent Initiation of Electro-Explosive Devices by Radio-Frequency Radiation
BSI, 1986

4.3 HEALTH AND SAFETY EXECUTIVE
Safety Notice 6/91
HSE Offshore Safety Division, 1991

Chapter 6 Pressure waves from explosions

6.1 NEDWELL, J R and THANDAVAMOORTHY, T S
The Waterborne Pressure Wave from Buried Explosive Charges: An Experimental Investigation
Jnl of Applied Acoustics, Vol 1 No 1, 1989

6.2 AARONS, A B
Underwater Explosion Shock Wave Parameters at Large Distance from the Chart
JASA, 26, 3, 1954, p 3143

6.3 NEDWELL, J R
Safe Standoff Distances for Swimmers Exposed to Underwater Blasting in Shallow Water
ISVR Technical Report 161, 1988, University of Southampton

6.4 JÖNSSON, A
Experimental Investigations on the Mechanisms of Lung Injury in Blast and Impact Exposure
Medical Dissertations No 80, 1982, Linköpuig University

6.5 CHRISTIAN, J and GASPIN, J
Swimmer Safe Standoffs from Underwater Explosions
US Navy Assistance Programme Report on Project PHP 11–73, 1974

6.6 DELIUS, M et al
Biological Effects of Shock Waves: Lung Haemorrhage by Shock Waves in Dogs – Pressure Dependence
Ultrasound in Medicine and Biology, 3, 2, pp 61–67, 1987

6.7 BRITISH STANDARDS INSTITUTION
BS 5607: 1988 Code of Practice for Safe Use of Explosives in the Construction Industry
BSI, 1988

6.8 PARVIN, S J and NEDWELL, J R
Underwater Sound Perception and the Development of an Underwater Noise Weighting Scale
Journal of the Society for Underwater Technology, London, Vol 21 No 1, Summer 1995

Chapter 7 Ground vibration and air blast

7.1 LANGEFORS, U and KIHLSTROM, B K
The Modern Technique of Rock Blasting
John Wiley and Sons Inc, New York, 1963

7.2 EDWARDS, A T and NORTHWOOD, T D
Experimental Studies of the Effects of Blasting on Structures
The Engineer, Vol 210, September 1960, pp 538–546

7.3 US BUREAU OF MINES
Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting
BuMines RI 8507, 1980

7.4 INTERNATIONAL STANDARDS ORGANISATION
ISO 4866: 1990 Guide for Measurement of Vibration and Evaluation of their Effects on Buildings
ISO, 1990

7.5 BRITISH STANDARDS INSTITUTION
BS 7385: 1990 Evaluation and Measurement for Vibration in Buildings. Part 1: Guide for Measurement of Vibrations and Evaluation of their Effect on Buildings
BSI, 1990

7.6 BRITISH STANDARDS INSTITUTION
BS 7385: 1993 Evaluation and Measurement for Vibration in Buildings. Part 2: Guide to Damage Levels from Groundborne Vibration
BSI, 1993

7.7 BRITISH STANDARDS INSTITUTION
BS 6472: 1992 Guide to Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz)
BSI, 1992

7.8 SISKIND, D E, STACHURA, V J, STAGG, M S and KOPP, J W
Structural Response and Damage Produced by Airblast from Surface Mining
BuMines RI 8485, 1980

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Appendix 1 Glossary

Words set in italic typeface in these definitions are defined elsewhere in the list.

Accessories (blasting)
Components used in conjunction with the main *explosive*. Accessories can be explosive (eg *detonators*) or non-explosive.

Air overpressure
The pressure greater than atmospheric produced in the atmosphere by the *detonation* of *explosives*. Consists of both audible (noise) and inaudible (concussion) energy, both of which can give rise to perceptible effects within structures.

ANFO
Ammonium nitrate fuel oil.

Arisings
Spoil resulting from a deliberate action.

Arming
Action of making an *explosive* ready to *fire*.

Base charge
In a composite *detonator* the *charge* of *secondary explosive* which amplifies the *detonating* impulse produced by the *primary explosive*.

Blast
A general term describing the effect produced when an *explosive* is *detonated* in any medium.

Blasting cap
See *Detonator*.

Blasting machine
Sometimes used to mean an ordinary *exploder* but usually refers to one with several output circuits which can be connected to individual or groups of *charges* to obtain precisely controlled and variable *firing* delays.

Blast injury
Detrimental changes occurring in an organism when it is being subjected to the pressure field produced by a *blast*. The changes may be produced directly or indirectly by the *explosive* phenomena.

Body waves
Seismic waves that travel through the body of the earth.

Booster
Alternative name for a *primer*, especially a large one. The two names are not always synonymous.

Canister
A container designed to take an *explosive* filling.

Cap
Alternative word for *detonator*.

Cap wires
See *Lead wires*.

Cartridge
A quantity of *explosive* in a wrapper.

Charge
A quantity of *explosive* appropriate for the work it is intended to do on its surroundings by releasing its stored energy.

Column charge
A composite *charge* where the greater part of a vertical *shot*hole in rock *blasting* is filled by a medium-strength composition.

Comp B pentolites
TNT mixtures with *RDX* and *PETN* respectively.

Cordtex
Trade name for *detonating cord.*

Cosmetic damage
The formation of hairline cracks in plaster, dry-wall surfaces and mortar joints.

Cut off
The severing of *detonating cord* by itself, causing interruption of the *detonation* process or *initiation* train.

Detonating cord
A flexible cord with a core of *high explosive* (usually *PETN*) at a specified loading which when *initiated* causes *detonation* along the cord and is capable of *initiating* a main *charge* or series of charges.

Detonation
Explosive decomposition proceeding faster than the velocity of sound in the *explosive.* Normal mode of action of *high explosives.*

> **Detonation pressure**
> The highest pressure reached in a detonating *explosive*; also known as the Chapman-Jouget or C-J pressure.
>
> **Velocity of detonation**
> Characteristic speed, for any given *explosive* and configuration, of the propagation of *detonation.*

Detonator
The usual item for *initiating* the main *charge* to *detonation.* Modern detonators consist of a metal or occasionally plastics cylinder containing a composite filling, a small pressed *charge* of (very *sensitive*) *primary explosive* to be ignited by *safety fuse* or electric match-head, and a slightly larger charge of a less-sensitive, *secondary explosive* to increase the effect. Also known as blasting *cap* (hence 'cap-*sensitive*').

> **Detonator strength**
> A number relating the initiating power of the *detonator* to the weight in grams of a mixture of mercury fulminate and potassium chlorate having the same *initiating* power.
>
> **Number 6 detonator**
> *Detonator* having the same *initiating* power as 1 g of fulminate/chlorate.
>
> **Number 8 detonator**
> *Detonator* having the same *initiating* power as 2 g of fulminate/chlorate mixture.
>
> **Star detonators**
> *Detonators* with higher strength than the number indicates, eg Number 6 Star and Number 8*, have greater initiating power than ordinary Number 6 and Number 8.
>
> **Plain detonator**
> *Detonator* open at one end to receive a *safety fuse.*
>
> **Electric detonator**
> *Detonator* intended for operation by the passage of an electric current through a bridge wire in the match-head. A sealed assembly.
>
> **Delay detonator**
> A *detonator* incorporating an additional delay between reception of the firing impulse and the ignition of the detonating composition. Several different delay times are available in 'half-second' and 'millisecond' series. Delay times are denoted by numbers which should not be confused with numbers denoting detonator strengths.
>
> **NPED**
> Non *primary explosive detonator*

Dynamite
Alternative name for *gelignite* (or *gelatine*). See also *NG.*

EBW
Exploding bridge wire *detonator* (see text).

EFI
Exploding foil *initiator* (see text).

Emulsion
Detonating *explosive* having almost the same ingredients as a *slurry,* in which the oxidising solution or melt is emulsified in an oily fuel as very fine droplets.

Exploder
Device, powered by battery or by turning a handle, which delivers a voltage at its terminals when a firing button is pressed or a key is turned, causing the *detonation* of one or more *detonators* connected in a firing circuit by wiring to the terminals.

Explosion
See *Blast.*

Explosive
Substance which can release energy and do useful work when it is converted very rapidly into largely gaseous products at the required time, by either burning or *detonating*. May be a single, more or less pure, compound or a mixture of substances which may or may not themselves be explosive.

Explosives technician
Technician responsible to the *supervising explosives engineer.*

Explosive strength
A measurement indicating the amount of work an *explosive* can do in normal use, expressed as a percentage of the work available from an equal weight or volume of a standard explosive in the same conditions (weight- and bulk-strength respectively). The standard explosive must be specified.

Firing
Action of applying the stimulus that brings about *initiation* of an *explosive.*

Fuse
See *Safety fuse.*

Gelignite/gelatine
Commonly used terms for *NG*-sensitised *explosive* composition. See also *Dynamite.*

Ground vibration
Movement of the ground produced by the *detonation* of *explosive charges.*

High explosive
An *explosive* which *detonates* in normal use.

HMX/octogen
Cyclotetramethylenetetranitramine, a *sensitive* and very dense *high explosive* with extremely high *velocity of detonation* and *detonation pressure.*

Hot work
In the context of these Guidelines, any work where a permit-to-work may be required because of risk from fire or explosion, eg welding, brazing, etc.

Initiation
The stimulus that starts an event or series of events leading to the *detonation* of a main *charge* or series of *charges.*

Initiator
The general term for a device which initiates the chemical and thermal processes which lead to the functioning of the main *charge* when the appropriate stimulus is applied. 'Igniferous' and 'disruptive' initiators are used to start burning and *detonation* respectively.

Instantaneous charge weight
The weight of *explosive detonated* at any one precise time.

Intermediary explosive
A *secondary explosive* of *sensitivity* higher than that of main charge *explosives* and with high *velocity of detonation* and *detonation pressure*, from which *primers* and *boosters* are made.

Lay-on charges
Surface *charges* of *explosives* sometimes used in demolition work for breaking large boulders and for underwater rock clearance.

Lead wires (cap wires)
Wires supplied with and an integral part of an electric *detonator.*

Magazine
A *store* for *explosives* sometimes with an integral annex for *accessories* (eg *detonators*). Licensed by the Health and Safety Executive.

Main charge or main filling
The bulk of *explosive* excluding those items needed to *initiate* its *detonation*. In most applications of explosives the main charge is a *secondary explosive*.

Misfire
Occasion when all or some of an *explosive round* fails to *detonate*.

NG
Nitroglycerine, or glyceryl trinitrate, an extremely powerful liquid *explosive*. Too *sensitive* for use alone. The main ingredient in the strongest *gelatines* and the explosive sensitiser in the lower ones and in semi-gelatines, gelignites and NG powder explosives. Also used as a main ingredient in gun and rocket *propellants*.

NONEL
Trade name for a non-electric (shock tube) system of *detonators* and *accessories*.

ODEX drilling
A system of cased drilling through *overburden* for blasting.

Overburden
Relatively soft formations overlying harder rocks which are to be blasted.

PE4
The abbreviation used for an *RDX*-based composition with a plasticiser added.

Perforator
Typically a cone-shaped *charge* for perforating drill casings in oil-bearing strata.

PETN
Pentaerythritol tetranitrate. *High explosive* used in *detonating cord*.

Primary composition
The substance in a *detonator* in which *detonation* originates; a mixture of *primary explosives* and other ingredients.

Primary explosive
A *high explosive* which almost instantaneously burns to *detonation* when even a small quantity is ignited. Usually very *sensitive* to all types of stimuli.

Primer
A small *charge* of an *intermediary explosive* interposed between *detonator* and *main charge* when the latter is not sufficiently *sensitive* to be *initiated* directly by the detonator. (See also *Booster*.)

Priming composition
A substance which converts electrically produced heat or mechanical energy into flash – sometimes called 'first-fire composition'. The *primers* encountered in *blasting* are not made from priming composition, although 'priming charge' might denote either a primer or a *charge* of priming composition.

Propellant
A substance or composition that is designed to burn very rapidly with the gaseous products used to create movement (eg in a rocket motor). Some propellants can *detonate* under certain confined conditions.

RDX/cyclonite/hexogen
Research Department Explosive. Alternative name for cyclotrimethylenetrinitramine, a *sensitive*, dense and powerful *high explosive*.

Round
A number of *charges* fired together, simultaneously (without intentional delay) or sequentially (with controlled delays). Sometimes used to denote the firing of a single charge, especially in gunnery.

Safety fuse
A flexible cord containing a burning medium with a pre-determined burning rate, generally used to initiate a plain *detonator* previously crimped onto the end and containing a small *base charge*.

SBG
Submarine blasting *gelatine*.

Secondary explosive
A *high explosive* with moderate or low *sensitivity* and usually, but not necessarily, with high *explosive strength*.

Sensitivity
The ease with which an *explosive* may be caused to function, intentionally or accidentally.

> **Figure of insensitivity (FOI)**
> A measure of the *sensitivity* of an *explosive* to mechanical impact. Height from which a drop-test weight must be released to give 50% ignitions, expressed on a scale in which *RDX* = 80 is a reliable standard value. A composition with FOI = 20 is very sensitive; one with FOI = 150 is comparatively insensitive.
>
> **Cap-sensitive**
> Able to be *initiated* to *detonation* by a *detonator* or 'blasting cap' directly without a *primer* or booster.
>
> **Cap-insensitive**
> Incapable of *detonation* by a *detonator* alone.
>
> **Cord-sensitive**
> Able to be *initiated* by a standard *detonating cord.*
>
> **Booster-sensitive**
> Unable to be made to *detonate* by a *detonator* or normal *detonating cord*; requires the greater effect of a *booster.*

Shaped charge
An *explosive charge* designed to utilise the 'lined cavity' effect, eg a cutting charge or perforator.

Shot
An individual *charge* and its associated *initiating* components, especially as one of a *round* of shots. Sometimes loosely used for any explosion whether a single or multiple charges are fired.

Slurry
Detonating *explosive* consisting of suspended solid nitrates and combustibles in a thickened oxidising solution, usually containing 5–12% or even up to 25% of water.

Stand-off distance
The range between an *explosion* and a given point. Stand-off distances of particular importance are those beyond which damage to structures and/or injury to personnel are unlikely.

Stemming
An inert material used to confine or separate *explosives* loaded into a borehole.

Stick
Usually a 7–8 ounce (200 g) stick of *gelignite* wrapped in wax paper, but could be smaller.

Store
A building licensed by the local authority and used to store *explosives.* See *Magazine.*

Sub-drilling
The drilling of a borehole to a depth greater than that to be blasted.

Supervising explosives engineer
The person ultimately responsible to the explosives contractor for *explosives* operations on a specific *work site.*

Surface waves
Seismic waves that travel near the ground surface.

Technician
See *Explosives technician.*

TNT
Trinitrotoluene, a powder or cast solid *high explosive.* Used as cast blocks for demolition. Used in powder form as the filling for *detonating cords.* Low melting point makes it a convenient and safe carrier for more powerful but more *sensitive explosives* which themselves have too high a melting point, or are insufficiently stable when molten, for casting alone.

Toe charge or bottom charge
At the far end of a shothole bored in rock, a high-strength *explosive* is needed to avoid leaving 'toes' or 'sockets'.

Work platform
The operational base from which *explosives* operations are carried out. Usually floating in the context of underwater explosives operations.

Work site
The entire area involved in an *explosives* operation.

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Appendix 2 Conversion tables

Pressure

To convert a measurement of pressure in a unit in the column heading to a measurement in a unit in the left hand column, multiply by the factor in the box where the appropriate row and column intersect.

	psi	**bar**	**Pa**	**kPa**	**Nm^{-2}**
psi	1	1.4×10^{1} (14)	1.4×10^{-4} (0.00014)	1.4×10^{-1} (0.14)	1.4×10^{-4} (0.00014)
bar	7.1×10^{-2} (0.07)	1	10^{-5} (0.00001)	10^{-2} (0.01)	10^{-5} (0.00001)
Pa	7.1×10^{3} (7100)	10^{5} (100,000)	1	10^{3} (1000)	1
kPa	7.1	10^{2} (100)	10^{-3} (0.001)	1	10^{-3} (0.001)
Nm^{-2}	7.1×10^{3} (7100)	10^{5} (100,000)	1	10^{3} (1000)	1

Impulse

To convert a measurement of impulse in a unit in the column heading to a measurement in a unit in the left hand column, multiply by the factor in the box where the appropriate row and column intersect.

	Pa.s	**bar.ms**	**psi.s**
Pa.s	1	10^{2} (100)	7.1×10^{3} (7100)
bar.ms	10^{-2} (0.01)	1	7.1×10^{1} (71)
psi.s	1.4×10^{-4} (0.00014)	1.4×10^{-2} (0.014)	1

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Appendix 3
Procedure for assessing possible radio hazards

A3.1 INTRODUCTION

The procedure in this appendix is intended as a preliminary check on whether there is any cause for concern about radio sources (RF emissions) in the vicinity of an explosives operation. In many cases it will lead to the conclusion that there is no problem and the only precaution needed is to remain alert to any change in circumstances that might affect the initial conclusion.

A3.1.1 Definitions

Frequency bands

It is usual to divide up the radio frequency spectrum into bands referred to by abbreviations such as 'MF' and 'VHF'. In considering radio hazards, the four bands of interest are:

• MF	300 kHz to 3 MHz
• HF	3 MHz to 30 MHz
• VHF	30 MHz to 300 MHz
• UHF	300 MHz to 3 GHz.

Power levels

For the purpose of an assessment of this type it is convenient to classify radio equipment into groups according to how much power it transmits:

• LOW power	less than 1 watt
• MEDIUM power	1 to 100 watts
• HIGH power	over 100 watts.

A3.2 PROCEDURE

A3.2.1 Survey

List all radio transmitters that could be in use on the site/platform/vessel at the time of the explosives operation.

List any other transmitters visible from the site.

Add any ship-board MF transmitters which could come within 10 km and any MF broadcast transmitters (ie medium wave or long wave) within a 100 km radius.

For each of the listed transmitters, collect the following data (Table A3.1 is an example of how to lay out the data and could form the basis for a spreadsheet):

- its distance (R) in metres from the explosive operations (or its closest approach if mobile)
- its lowest operating frequency (F) in MHz (initially it may be enough to know the frequency band)
- its output power (P_T). If the transmitter can be classified as LOW or MEDIUM power, this may be accurate enough, but if it is likely to fall into the HIGH category, a specific figure should be obtained for P_T
- gain of transmitting aerial. Does the transmitter beam most of its power in one direction? If so, and the beam could point towards an area where detonators are being handled, find out the numerical gain (G_D) of the aerial relative to a dipole, and multiply P_T by G_D to obtain a figure P_{TRANS} for the 'effective transmitted power'. If the aerial is designed to radiate uniformly in all directions, take G_D to be 1.

Proceed to assess the hazard either by calculation (Section A3.2.2) or by graphical method (Section A3.2.3).

Table A3.1 **Examples of collection of data on transmitters**

Transmitter		**Minimum distance**	**Lowest frequency**		**Maximum output power**		**Aerial gain**	**Effective trans. power P_{TRANS}**	**Received power**
Ref No	**Description**	**(R in metres)**	**(Band)**	**(F in MHz)**	**(L/M/H)**	**(P_T in watts)**	**(G_D)**	**(P_T x G_D in watts)**	**(P_{RECEIVED} in watts)**
1	Hand held	1	UHF	400	LOW	0.5	1	0.5	0.0048
2	Shore link	22	VHF	(Assume 30)	MEDIUM	(Assume 100)	12	1200	4.19
3	Shore link	22		120		10	12	120	0.026
4									
5									
Etc									

The examples in this table are fictitious and should not be taken as typical of actual transmitters.

If the example given as Ref No 1 were the only transmitter in use, the conclusion would be 'NO PROBLEM' for detonators with a safe power level P_{SAFE} of 0.04 watts.

Ref No 2 has been assessed approximately, as a VHF transmitter of medium power. It gives a 'POSSIBLE PROBLEM' conclusion.

In Ref No 3, the same transmitter has been reassessed with exact data for frequency and output power. This time the conclusion is changed to 'NO PROBLEM' for P_{SAFE} of 0.04 watts, although not by a large margin.

A3.2.2 Calculation

For each transmitter, calculate the amount of RF power (P_{RECEIVED}) in watts that could reach a detonator by using the equation:

$$P_{\mathrm{RECEIVED}} = P_{\mathrm{TRANS}} (39/FR)^2$$

For transmitters that are being assessed by category of output power, not measurement, take LOW power to be 1 watt and MEDIUM power to be 100 watts. If only the band of the frequency is known, assume it is at the bottom of the band (eg VHF would be 30 MHz).

Add up the P_{RECEIVED} figures for all the transmitters on the list.

Obtain a safe power level (P_{SAFE}) for the most sensitive detonator type to be used. If the manufacturer's data gives only a no-fire current (I_{SAFE}), P_{SAFE} is given by:

$$P_{\mathrm{SAFE}} = (I_{\mathrm{SAFE}})^2 \text{ x (detonator resistance)}$$

For example, if 1 ohm detonators are in use and they are known to be completely safe at currents up to 200 mA, P_{SAFE} is 0.04 watts.

If the total of the P_{RECEIVED} values is less than P_{SAFE}, the conclusion of the assessment is 'NO PROBLEM'.

If the P_{RECEIVED} total exceeds P_{SAFE}, the conclusion is 'POSSIBLE PROBLEM' and further action should be taken – see Section A3.3 below.

This calculation method assumes that the detonator wiring picks up RF power as efficiently as a dipole receiving aerial (see Section 4.5.3). Directional characteristics of any of the transmitting aerials will have been taken into account in Section A3.2.1 above when converting from P_T to P_{TRANS}.

A3.2.3 Graphical method

Figure A3.1 can be used to make an approximate evaluation of the RF hazard from each transmitter. Transmitter Ref No 3 from Table A3.1 has been drawn on the figure as an example. To use the nomograph, mark the closest approach distance of the transmitter to the explosives operation on Scale A and its frequency on Scale B. Draw a straight line between these two points. Its intersection with Scale C in the middle of the figure shows the highest acceptable value of transmitter power, assuming a detonator with a safe power level of 0.04 watts.

The highest acceptable value of power for transmitter Ref No 3 is shown by the nomograph to be nearly 200 watts.

Overall, the following conclusions can be drawn:

- as the effective transmitted power (P_{TRANS}) for transmitter No 3 is 120 watts (see Table A3.1), this transmitter on its own is 'NO PROBLEM' – but only by a factor of about 1.5 to 1

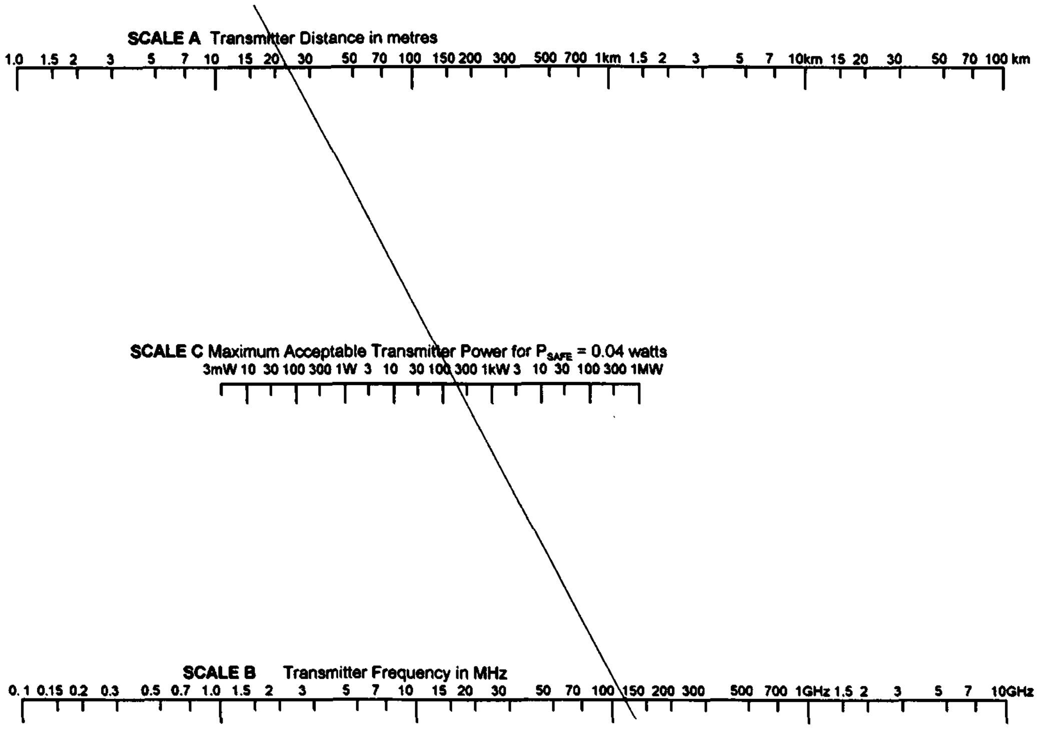

FIGURE A3.1 - GRAPHICAL EVALUATION OF HAZARD

Figure A3.1 **Graphical evaluation of hazard**

- if each transmitter on the list can be rated 'NO PROBLEM' by a factor of at least 10 to 1, the overall conclusion can be taken to be 'NO PROBLEM'
- if each transmitter can be rated 'NO PROBLEM' but two or more of them pass by a factor of less than 10 to 1, the overall conclusion should be taken as 'POSSIBLE PROBLEM', and consideration should be given to checking the result by the calculation method in Section A3.2.2 above or proceeding directly to Section A3.3 below
- if any transmitter is rated 'POSSIBLE PROBLEM' on its own, ie its P_{TRANS} is greater than the maximum acceptable transmitter power (P_{SAFE}) for the detonators in use, the overall conclusion must be 'POSSIBLE PROBLEM'. Further action is needed – see Section A3.3 below.

A3.3 WHAT TO DO IF THE CONCLUSION IS 'POSSIBLE PROBLEM'

If any conclusion of 'POSSIBLE PROBLEM' is reached, one or more of the following steps should be taken, followed by a repeat of the calculation and evaluation procedure where appropriate.

- If the problem arises from a transmitter for which only approximate frequency and power data are available (eg 'MF' and 'medium power'), obtain exact data.
- Is it possible to ensure that troublesome transmitters stay further away from the area where detonators are being handled? An increase in the closest approach distance R by a factor of 2 reduces $P_{RECEIVED}$ by a factor of 4. Figure A3.1 can be used 'backwards' to calculate how far away a given transmitter would need to be. A line can be drawn from the frequency scale through the actual value of P_{TRANS} on the centre scale. The point at which the new line intersects the distance scale indicates the closest safe distance for that transmitter.
- Can *all* of the explosives work be carried out with less sensitive detonators, eg using 50 ohm devices instead of 1 ohm? This has the effect of increasing P_{SAFE}.
- Radio silence should be regarded as a last resort since shutting down radio systems has other consequences, possibly some with safety implications. If this action is to be taken, it should be clear from the calculation/evaluation which transmitters need to be shut down.
- Seek specialist guidance.

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Appendix 4 Training

Types of training

All personnel involved with explosives should be competent in the area of work they are about to undertake and should have undergone some form of appropriate and recognised training. Training may be one or a combination of:

- *Academic and theoretical*
  The theory behind explosives and the chemical reactions created are covered in a variety of scientific and engineering degree courses, but there is no degree course in the UK entirely devoted to the use of explosives. Cranfield University, through its RMCS Campus, does offer an MSc course in ballistics and explosives, but this is aimed primarily at service personnel or civilians working for the military.
- *Services*
  The armed services and police provide practical and theoretical training to a high standard. The rank/rate achieved indicates the types of courses and training which an individual is likely to have undergone. Military training covers theory, formal courses and on-the-job training.
- *Company courses*
  Responsible specialist explosives companies run in-house training courses to ensure their personnel understand fully how the company's specialist charges work and how they should be used. The type and length of training is dependent on how non-standard the charges are, what they are to be used for, the range of types available and local national legislation.
- *External training courses*
  External training courses are run by several organisations including explosives manufacturers, the Institute of Explosives Engineers and technical colleges. There is no central accreditation body for explosives courses, and advice should therefore be sought before attending any external course. The Institute of Explosives Engineers has endorsed a number of courses and their updated list can be obtained from:

  The Institute of Explosives Engineers
  Centenary Business Centre
  Hammond Close
  Attleborough Fields
  Nuneaton
  Warwickshire CV11 6RY
  Tel: 01203 350846
  Fax: 01203 350831
- *On-the-job training*
  On-the-job training (OJT) is by far the most important form of training for an underwater explosives engineer or technician, as many underwater tasks cannot be completed only on the basis of text book study. OJT should be as thorough as possible and cover the complete range of tools used by the company. Experienced personnel should supervise OJT and records should be kept. Trainees should be given tasks to complete and should be encouraged to use any experience they have already gained.

Wherever possible, companies should use the full extent of training methods available so that their employees can continue to grow in knowledge and become familiar with new methods, explosives and materials as they come onto the market.

Record of training

A record of all training received should be kept by each individual and by his employer.

Explosives engineers and technicians should also keep a record of all the jobs they have been involved in. The Institute of Explosives Engineers has produced a log book to make the recording easier. Log books can be used to demonstrate that an individual has actual experience of a particular type of job or that his overall experience should be sufficient to enable him to tackle something new.